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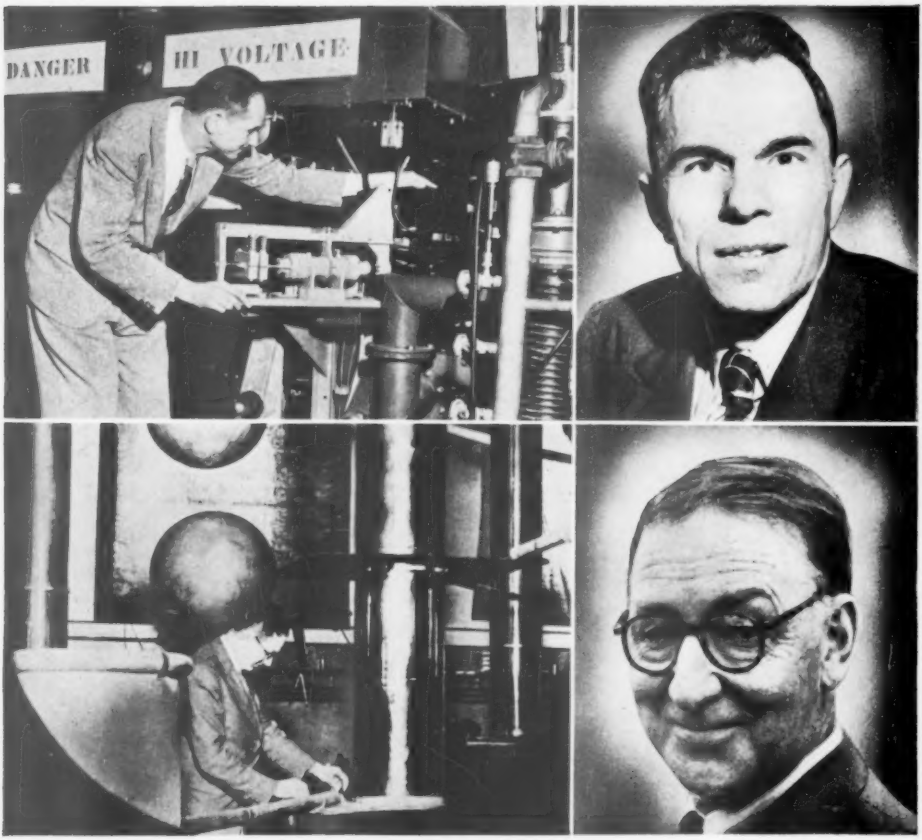

1951 Nobel Prize Winners in Chemistry (top row, Edwin M. McMillan and Glenn T. Seaborg) and in Physics (bottom row, E. T. S. Walton and Sir John D. Cockcroft) honored for their discoveries and pioneer work in nuclear science

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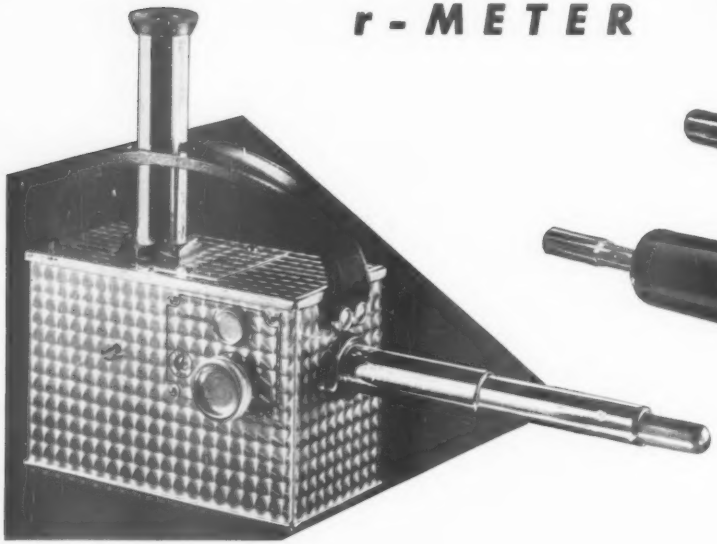

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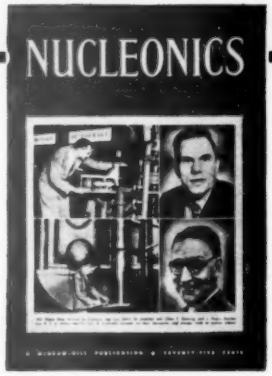

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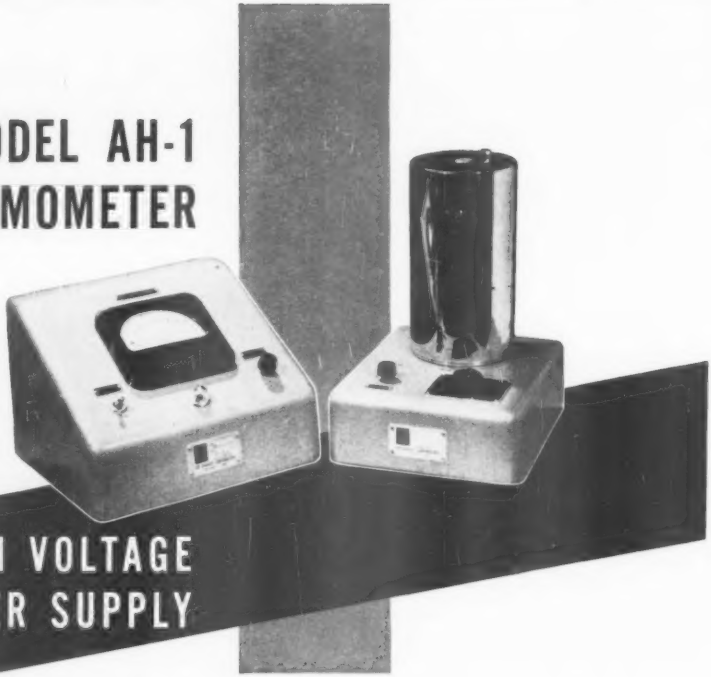

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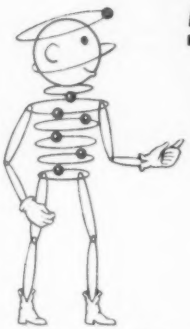

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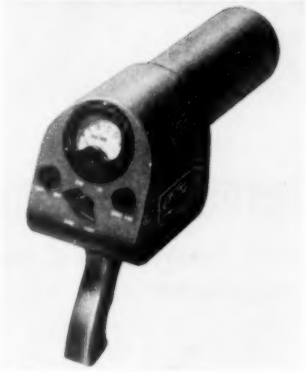

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GENERAL ELECTRIC

687-87

Expansion

This issue—Vol. 10, No. 1—represents an important milestone in the history of NUCLEONICS. With it, we are taking a major stride forward, a stride which is in keeping with the steady growth of the atomic energy field in the postwar period.

The basic purpose of this larger format and a planned expansion of editorial scope is to enable us to serve our readers better. So far as any pot of gold is concerned, we are building for the future, a future in which there will be a thriving peacetime atomic industry.

What does this expansion mean for our readers?

1. *Increased physical dimensions*—The most apparent change we have made is to increase the size of our format. We are sure that this will be greeted by groans from those who found our previous "pocket size" to be convenient. However, the advantages of the larger size are so great that the change was inevitable. We will now have greater flexibility in the physical display of articles. All drawings, photographs and tables can be increased in size. Material which we were unable to use previously, because of inconvenient dimensions, will now fit into our pages.

2. *Editorial scope*—To date, NUCLEONICS has been edited primarily for the man interested in keeping up with the technical developments in atomic energy. To this end, we have solicited editorial material in all phases of the field—including all branches of engineering and the physical and life sciences. And we have been pleased to note the increasing use of our articles right at the laboratory bench.

In our new size we are not going to take anything away from this technical coverage, either in scope or in quantity. Instead, we plan to add to it. With more and more people becoming interested in the atomic energy field, we feel that it is our responsibility and function to serve this broadening audience. Over the course of the next six months to a year, articles of a type which have appeared only sporadically over the past four years will begin to appear regularly in the pages of NUCLEONICS; for example: broad-interest, nontechnical or semitechnical interpretive articles, placing in perspective technological developments; broad-interest technical review articles; practical, "how to" material; and progress reports on work and facilities at atomic energy laboratories all over the world. In the months to come all of this will be added to our previous technical coverage.

3. *Speed of publication*—In the past, we have been able to offer our authors comparatively quick publication—usually no longer than three months from date of acceptance. With our present expansion, we shall be able to increase this speed to two months in many cases.

What is the relationship of our expansion to the status of the atomic-energy field?

With atomic energy making the headlines every day there should be no question about the growth of this field; but it is worth noting some recent pertinent events. (The following items are highlights taken from more detailed articles in this issue.)

1. *Third major expansion of AEC program*—Serious consideration is being given to the proposal made by Senator McMahon that a $5-billion expansion be carried out. Under the present program, the Atomic Energy Commission will soon have facilities larger than those of U. S. Steel and General Motors combined. If the contemplated expansion is put into effect, the impact on our economy will increase perhaps by several hundred fold.

2. *Industrial participation*—Statements by commissioners and others within the AEC scope of activities make plain that much greater participation by industry is desired not only to strengthen the AEC program but to benefit our industrial economy. To get more industrial interest in the program, it is realized that more information about the program must come out where it can be seen and read by industry; and recent events indicate that numerous steps in this direction are being made.

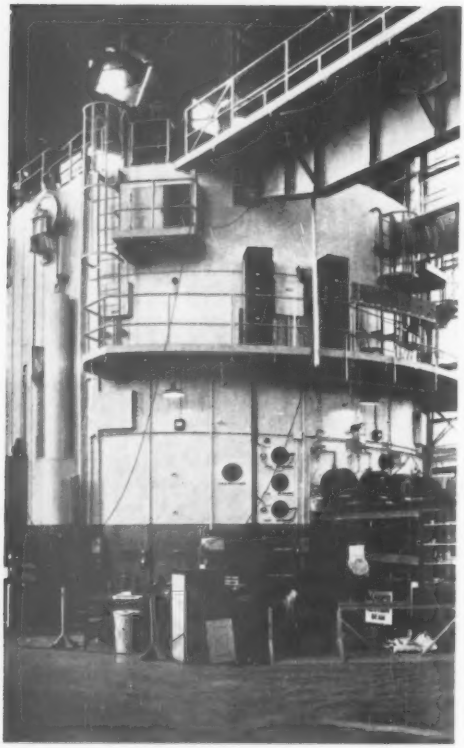
3. *Nobel prize winners*—The atomic energy field continues to dominate the awards in the natural sciences. The four prizes given in physics and chemistry last month were to men who made important contributions to the advancement of nuclear science. It is likely that with the growing number of people working in this field progress will continue to be made at a fast pace.

4. *Energy from reactors*—The first use of the heat developed by a nuclear reactor was announced by the British last month. Although heating one of their buildings with the heat from their large reactor has no great economic significance, it is a step in the right direction. The way to find out about the feasibility of nuclear power plants is to build them.

5. *The future*—We are still not in a position to know what the future holds for us in this field. The only way we can learn is by "doing." Last month, Dr. Harold Urey and Dr. F. Seitz called on the AEC to do just this, to be more aggressive and daring. And, in a look into the next 50 years, Dr. Charles Allen Thomas, president of the Monsanto Chemical Co., said, "I believe that some have underrated American technological genius when they assert that atomic energy will not supply a significant proportion of the power needed for our increased production. Our engineers and technologists will see to it that valuable fissionable materials will be produced simultaneously with electrical energy at a competitive cost. The breeder reactor will be a reality and the disposal of waste from our atomic reactors will be controlled."

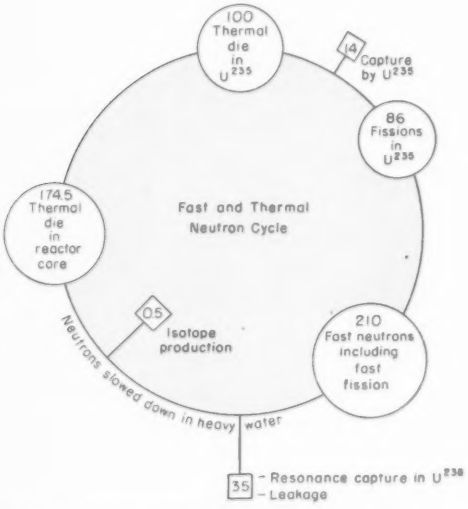
—*J. D. L.*

Canadian Facilities for Isotope



THE NRX REACTOR at Chalk River, Ontario, provides a neutron flux of over 5×10^{13} neutrons/cm²/sec. . .

F. W. GILBERT, Assistant Manager in the operations division of the Canadian Atomic Energy Project, discusses the limitations and capabilities of the reactor having the world's highest neutron flux



BUT ONLY a small part of this flux is available for isotope production and bombardment. . .

CANADA's National Research Council constructed the NRX reactor for use as an instrument of research. Of necessity most of the research must be done at or near the reactor itself. But both pure and applied research at other laboratories is aided through the reactor facilities for irradiation of materials by neutrons. These irradiation facilities are available not only for research in Canada, but for approved projects elsewhere.

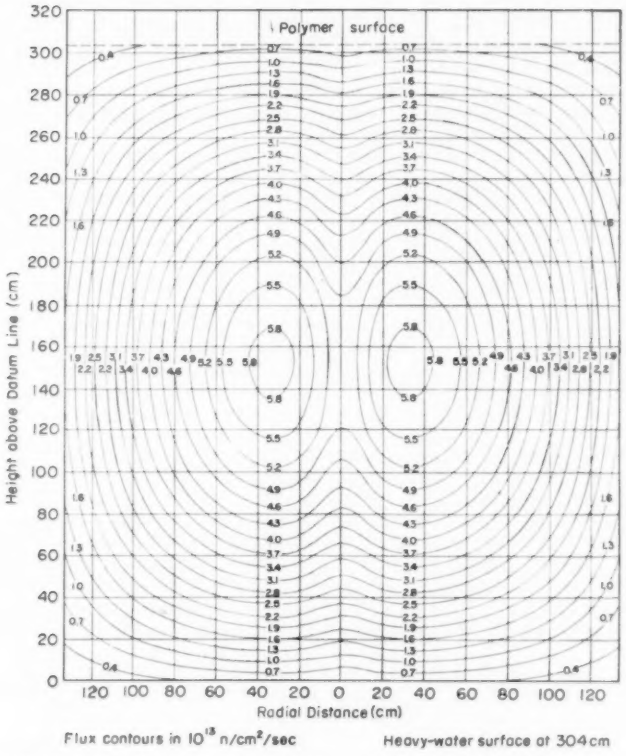
Like all reactors, this one has specific capabilities and specific limitations. The most advantageous use of the irradiation facilities is achieved only if these capabilities and limitations are understood. This is particularly true because the facilities are limited and in great demand.

This natural-uranium, thermal-neutron reactor is moderated with heavy water. It normally operates above the 10,000-kw power level for which it was designed. The main reacting vessel is about 8 ft in diameter and 10 ft high. In it 176 uranium rods are encompassed by the heavy-water moderator. A movable control rod is used for regulation. The reacting vessel is enclosed in a graphite reflector and a concrete shield about 8 ft thick. Materials to be irradiated can be inserted from the sides and from the top of the reactor. Water from the Ottawa River is used as a cooling medium for the reactor.

Because heavy water is a more efficient moderator of neutrons than graphite, the reacting core of the NRX reactor is smaller than the core of a graphite-moderated reactor of comparable power. The power of a reactor is directly related to the number of fissions taking place. Also, of course, the number of neutrons emitted depends upon the number of fissions. Therefore, the smaller the volume of a reactor for a given power, the greater

* From a paper presented at the 12th International Congress of Pure and Applied Chemistry, New York, Sept. 10, 1951.

Production and Bombardment*


Polymer surface
Height above Datum Line (cm)
Radial Distance (cm)
Flux contours in 10^{13} n/cm²/sec
Heavy-water surface at 304 cm

AND THE HIGHEST neutron flux is confined to a very small area in this heavy-water moderated, nuclear reactor

is the neutron density and hence the neutron flux.

The result of the smaller volume for a high power, achieved in the NRX reactor, is that the thermal-neutron flux is greater than in any other known reactor. This characteristic is not necessarily an advantage for the production of plutonium, but it is extremely valuable for the production of some isotopes.

Advantages of High Flux

The maximum flux of over 5×10^{13} neutrons/cm²/sec is the most significant feature of this reactor. A few simple mathematical considerations will show some of the advantages of this high flux.

The rate of formation of neutron-produced atoms in a reactor is given by the relationship

$$dN/dt = n\sigma F - N\lambda \qquad (1)$$

where N = the number of product atoms existing after time t, n = the number of target atoms, σ = capture cross section in cm², F = flux in n/cm²/sec, and λ = radioactive decay constant, equal to $0.693/T$ where T is the half-life of the product formed by irradiation. The first term of this relationship gives the rate of formation of product atoms whereas the second gives the rate of decay of these radioactive atoms.

By definition, saturation is reached when N is a maximum or when the differential is zero. Under these circumstances

$$N = n\sigma F/\lambda \qquad (2)$$

From this it can be seen that the saturation activity is directly proportional to the flux. Thus, in a flux of 5×10^{13} n/cm²/sec, it is possible to achieve specific activities ten times as great as can be obtained in a flux of 5×10^{12}. This means that a sample can be used for three more half-lives before the limit of detection is reached. In some cases the higher specific activity allows use of samples that previously fell below the threshold of detectability.

The value of the high flux is greater still when studying successive transformations, since the saturation activity of the second successive product varies as the square of the flux. This could be useful for studying an isotope such as Na^{25}. This isotope can be produced by the irradiation of Na^{23} to form Na^{24}, which under further bombardment will form Na^{25}. In the usual symbols, this is shown as: $Na^{23}(n,\gamma)\,Na^{24}(n,\gamma)\,Na^{25}$. Using the relationship given in Eq. 2 for the saturation activity

$$N = n\sigma_1\sigma_2F^2/\lambda_1\lambda_2 \qquad (3)$$

where N is the number of atoms of Na^{25}, σ_1 and σ_2 the capture cross sections of Na^{23} and Na^{24}, respectively, and λ_1 and λ_2 the radioactive decay constants of Na^{24} and Na^{25}.

The more general solution of Eq. 1 for $N \ll n$ is

$$N = \frac{n\sigma F}{\lambda}\,(1 - e^{-\lambda t}) \qquad (4)$$

Using this equation to calculate the time required to produce a specific activity of 20 curies/gram of Co^{60}, we find that six months are required in a flux of 5×10^{13} n/cm²/sec, whereas 97 months are required in a flux of 5×10^{12}. The ratio of the irradiation times is not 10 but 16. This, of course, is caused by the decay of the Co^{60} during irradiation, even though the half-life of Co^{60} is 5.3 years. An ir-

radiation time of 97 months without allowing for pile shut-down time is essentially beyond practicability for production, but still there is a large demand for high-specific-activity Co^{60} for use in γ-ray therapy.

The high flux, then, is very valuable for materials both of short and relatively long half-life. It is a disadvantage where successive transformations are to be held to a minimum, such as for production of Hg^{198}. In cases like this, suitable low fluxes are available in the NRX reactor.

Effect of Cross Section

In actual practice the preceding calculations are applicable only for the simpler irradiations such as small quantities of material having a very low cross section for thermal neutrons. As soon as the total cross section of a material becomes appreciable, other factors must be considered.

The first factor is the effect of the material on the flux. It is the usual practice to refer to the neutron flux in a given position as that flux which is present in an empty hole. As soon as material is added, the flux decreases by an amount that depends on the total absorption cross section and concentration of the material.

A correction must also be made for the attenuation of the neutrons in passing through a substance. Because of attenuation, a sample does not have the same number of neutrons bombarding its center as bombard its periphery. And, since the flux in the reactor is omnidirectional, the total number of neutrons reaching any outer face of a sample is also decreased. The correction factor for this attenuation must be applied for all samples introduced into the reactor; it increases and approaches unity as the sample thickness approaches monatomic or as the true cross section approaches zero.

These two major effects can make it necessary to apply a correction factor of less than 0.5 to the flux in irradiation computations, or the irradiation time may be more than doubled. The obvious way to improve this condition is to distribute the material through a large section of the reactor. However, there are practical limits to the space available, and a compromise is usually necessary.

One of the limitations of the NRX reactor is illustrated by the sketch on page 18 depicting utilization of neutrons in a heavy-water reactor. In this diagram the starting point is at the top with 100 thermal neutrons. The cycle proceeds clockwise, returning to the starting point to give the steady-state reaction.

Neutron Economy

The percentage of neutrons that can be removed is very small. If more are removed there will not be enough left to maintain the chain reaction. One cannot go on indefinitely placing neutron absorbers into the reactor, and the most efficient use of the available neutrons must be carefully considered.

Unfortunately, the diagram illustrates the total reactor conditions without regard for the section of the reactor from which the neutrons are removed. A neutron born a maximum distance from the walls of the reactor is less likely to be lost through structural capture or leakage than is one originating near an external wall. Conversely, such a neutron is more likely to be captured by the uranium to cause fission and maintain the chain reaction. Therefore, removal of neutrons from the central portion of the reactor has a greater effect on the reactivity than the removal of outer neutrons. To a first order of magnitude, the effect of removal of neutrons varies as the square of the flux.

Consider how this affects the irradiation of an absorber such as cobalt. If two 10-gm samples are placed successively in the highest flux for six months each, there will result a production of some 400 curies of Co^{60} in one year. For the same effect on the reactivity, it is possible to place four times as much material in a region having half the flux. Therefore, at half the flux it is possible to insert 40 grams, which in a period of about 13–14 months will give 800 curies of Co^{60}. Thus, for about 10% increase in irradiation time, twice as much production can be achieved. As the number of neutrons available for irradiation is not unlimited, it is therefore desirable to use lower flux positions whenever possible.

Flux Distribution

The flux distribution for a cross section through the center of the NRX reactor is given on the preceding page. A three-dimensional distribution could be obtained by rotating this chart through 180 degrees. The maximum flux shown is 5.8×10^{13} n/cm^2/sec. However, this flux occupies only a small part of the volume of the total reactor vessel. Furthermore, most of this volume is needed for reactor materials, leaving a still smaller fraction for irradiation of materials.

This places another limitation on the use of the highest flux in the reactor. There is a shortage of irradiation space. It is only natural that, as this part of the reactor gives the highest neutron flux available anywhere in the world, it is in very great demand.

This shortage of space, of course, is the limitation placed on the degree to which highly absorbing materials can be distributed so as to maintain the high flux and to reduce neutron attenuation. The answer to the problem usually comes in a compromise by using lower flux regions. A study of the chart will show that there is a considerable volume of the reactor with higher fluxes available than in other reactors. In the case of highly absorbing materials, it is sometimes possible to distribute them in the lower flux so as to have nearly the same net effect as if they were compacted in the high flux.

One other factor must always be considered before any material is placed in the reactor—will any chemical change of the material endanger the reactor? For example, organic materials tend under irradiation to alter to acids, carbonates to decompose, and crystal structures to change in size and shape. All these changes can be hazardous to a reactor. Fortunately, it is usually possible to select a material acceptable to both the experimenters and the reactor operators.

Handling of Product

Naturally, before any material is placed in the reactor, some thought must be given to handling it after activation. For most activity levels, the equipment at the project is adequate. For highly active materials, it has frequently been necessary to devise new techniques, but to date no sample has ever been refused because of difficulties in handling on removal. One of the more recent problems has been the removal and transfer of some 3,300 curies of Co^{60} having a specific activity of 23 curies/gram. This could have been done relatively easily under water, but for various reasons it was necessary to do it dry and in an unsealed condition. This has been done.

Secondary Electron Emission and Effective Atomic Numbers*

The interaction of gamma rays with matter depends on the absorber's atomic number. Effective atomic numbers of composite materials can be found from studies of secondary electron emission

By GERALD J. HINE†
Laboratory for Nuclear Science and Engineering
Massachusetts Institute of Technology
Cambridge, Massachusetts

THE WELL-KNOWN γ-ray absorption coefficients, τ, $\sigma = \sigma_a + \sigma_s$, and κ, for the photoelectric effect, the Compton process, and pair production, respectively, allow an accurate estimate of the interaction of γ-rays of a given energy with matter of known composition. Whenever a γ-ray is absorbed by one of these three processes, a secondary electron is produced. Its energy depends on various factors, the energy of the primary γ-ray, the type of γ-ray interaction, the atomic number of the absorbing matter, and the direction of emission.

The various theories which describe the different absorption processes predict the energy and intensity distribution of the emitted secondary electrons. The calculated data are in good agreement with the experimental results for γ-rays absorbed in gases or very thin foils.

If the γ-rays are absorbed in a thick layer of material, comparable with the range of the secondary electrons, or even thicker, the original energy and intensity distribution of the secondary electrons will be altered considerably. The secondary electrons will lose energy by ionization and radiation processes and will change their direction of passage through the absorber as a result of single and multiple nuclear scattering. The detailed evaluation of these interactions is rather complicated since the nuclear scattering depends on the energy of the electron and on the atomic number of the absorber. Therefore, few predictions can be made concerning the energy and intensity distribution of the secondary electrons emitted from a thick γ-ray absorber. However, for a number of problems, at least some information concerning the directional emission of secondary electrons is of great importance.

Secondaries from Radium Gammas

Until recently radium was the only γ-ray source generally available. Very extensive studies have been made of the absorption of its γ-rays in various materials and of the associated production of secondary electrons. Since the radium γ-ray spectrum is very complex, no general conclusion concerning the variation of the different observations with the γ-ray energy could be made. However, the measurements indicate the characteristic dependence of the secondary electron production on the atomic number of the absorber.

Some investigators (*1, 2*) have used air-wall ionization chambers with provision for the replacement of one part of the chamber wall by a medium of higher atomic number than the air equivalent substance (carbon). The contribution from the remaining parts of the chamber to the total ion current cannot be evaluated from this type of measurement. Therefore, the secondary electron emission of various materials can only be given relative to that of a low-atomic-number material plus an unknown fraction due to the rest of the chamber.

Including the present measurements, which will be described in the next section, a number of authors (*3–6*) have therefore employed a somewhat different type of ionization chamber. The walls of these chambers are made of as little material as possible, so that the emission of secondary electrons from the chamber walls is a minimum. The residual ion current caused by some γ-ray absorption in the very thin walls and the air volume of such an ionization chamber, can be regarded as chamber background. By building up one of the chamber walls to a thickness such that the secondary electron emission from this particular absorber reaches a maximum, the emission of various materials can be compared with each other. Furthermore, the contributions of the front and back wall of the chamber can be investigated independently of each other.

Figures 1 and 2 show the results obtained with radium by four different groups of investigators. Even though

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

† Special Research Fellow of the National Cancer Institute, Bethesda, Maryland.

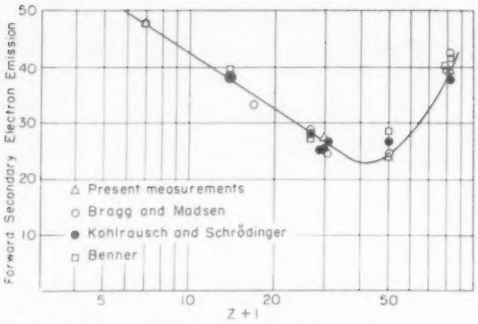


FIG. 1. Forward secondary electron emission from radium gamma rays as a function of $\log(Z + 1)$ of the absorber

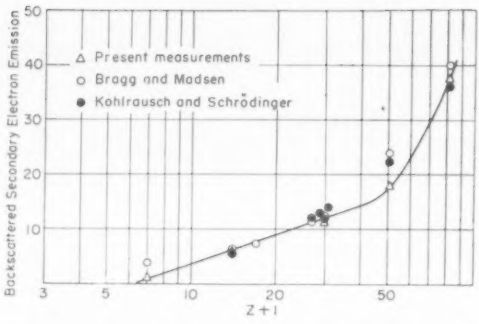


FIG. 2. Backscattered secondary electron emission from radium gamma rays as a function of $\log(Z + 1)$ of the absorber

the experimental arrangements employed by each group are rather different, the results agree remarkably well.

In Fig. 1 the ionization intensity produced by secondary electrons emitted in the forward direction by various γ-ray absorbers is given as a function of the atomic number, Z, of the material. The values for $(Z + 1)$ are plotted on a logarithmic rather than a linear scale. The data given by the different authors have been adjusted to the same value for the carbon absorber. The general shape of this curve is also in good agreement with the one obtained by those authors (*1, 2*) who have used air-wall ionization chambers. The secondary electron emission in the forward direction decreases from low-Z materials until $Z \sim 40$, and rises again towards the high-Z elements. The reasons for this behavior will be explained in the next section.

Evidence will be given later that the variation of secondary electron emission in the forward or backward direction (so far only Compton electrons are concerned) is caused by the different amount of electron scattering in the various materials. The Coulomb scattering by atomic nuclei (multiple scattering) is proportional to nZ^2, where n is the number of atoms per cubic centimeter of absorber and Z is the atomic number of the absorber (*7*). The energy loss for electrons in collision with the atomic electrons is proportional to nZ, the number of electrons per cubic centimeter of material. Therefore, the total scattering probability is proportional to $n(Z^2 + Z)$ or $1/A(Z^2 + Z)$, since $n = N\rho/A$. Finally, with the approximation Z/A = constant, the scattering of electrons is proportional to $Z + 1$ of the medium.

The backward emission of secondary electrons produced by the radium γ-rays increases with increasing atomic number of the absorber as shown in Fig. 2. This saturation backscattering of secondary electrons has been measured with a thick chamber back wall and no γ-ray absorption in the front wall. Here again the results of the different investigators are in good agreement. The saturation backscattering has been plotted in Fig. 2 as a function of $\log(Z + 1)$ of the absorber. A more detailed discussion of these results will follow in a later section.

Energy Dependence of Secondaries

The results described so far with the γ-rays of radium do not permit any general conclusions because of the complexity of the energy spectrum. The measurements have therefore been repeated with nuclides that emit nearly monochromatic γ-rays (*8*). Table 1 shows the different isotopes used, their half-lives, and their γ-ray energies. The relative intensities of γ-rays of different energies emitted from each nuclide are also given.

The various γ-ray sources are placed inside a lead cone which collimates the γ-rays through two adjacent ionization chambers; each chamber is a cube about 5 in. on a side. With the exception of a Lucite bottom plate, the chamber walls are made of very thin aluminum foils (0.00025 in.) supported by four rods at the corners of each chamber.

Absorbers of various materials are put vertically into the 1-cm-wide opening between the two chambers, as indicated in Fig. 3. For each γ-ray energy the absorber thickness is chosen approximately equivalent to the range of the secondary electrons. By means of a magnetic field between the γ-ray collimator and chamber A, the secondary electrons emitted from the collimator are deflected. Therefore, for a given γ-ray source, the ion current in each chamber, with no absorber between them, is regarded as chamber background. A lead absorber always yields an ion current in each chamber of about twice the background reading. A Beckman Model MX-4 radioactivity meter is employed as a measuring instrument.

A small fraction of the secondary electrons are emitted nearly parallel

TABLE 1—Gamma-Ray Energies of Various Nuclides

Isotope	*Half-life*	*Gamma-ray energy (Mev)*	*Relative intensity*
Na^{24}	15.0 h	2.758	0.5
		1.380	0.5
Co^{60}	5.3 y	1.332	0.5
		1.172	0.5
Zn^{65}	250 d	1.12	0.95
		0.511	0.05
Cs^{131}	2.3 y	0.794	0.44
		0.602	0.44
		0.568	0.12
Cu^{61}	3.3 h	0.511	1.0
Au^{198}	2.7 d	0.411	1.0
Hg^{203}	46 d	0.280	1.0

to the absorber and will be lost in the 1-cm-wide gap between the two chambers. Neglecting this fraction, the total ion current from both chambers is a measure of the total secondary electron emission from the absorber between both chambers. Figure 4 shows the results obtained with six of the different γ-ray emitters listed in Table 1. The values are normalized to the emission from carbon absorbers and are plotted as a function of $\log(Z+1)$.

In Fig. 4 the variation of Z/A as a function of Z for each element is also included (dotted line) since the emission of Compton electrons is proportional to Z/A. The results given in Fig. 4 show that the secondary electron emission from materials irradiated by γ-rays with energies above 1 Mev decreases with increasing Z of the absorber somewhat more rapidly than Z/A. This may be explained as follows. The scattering of the secondary electrons increases with increasing atomic number of the material. That means that the path length of the secondary electrons within the medium increases with Z and, therefore, its effective thickness (in mg/cm^2) for the emission of Compton electrons appears to be reduced for high-Z materials.

The rise of the secondary electron emission curves shown in Fig. 4 for high-Z absorbers is caused by the production of photoelectrons in addition to the Compton electrons. In aluminum, only γ-rays with energies less than 300 kev can produce photoelectrons of significant intensity in comparison with the Compton electron emission. The same is true for γ-rays with energies of less than 500 kev for copper absorbers and less than about 1 Mev for tin absorbers. Gamma rays of nearly all energies can be absorbed in lead by the photoelectric process which shows a rapidly increasing contribution with decreasing γ-ray energy. All these facts are in good qualitative agreement with the experimental data presented in Fig. 4.

Backscattered Secondaries

So far the total ion current resulting from both chambers, in front and behind the absorber, has been considered. The variation of the secondary electron emission in the forward direction and also the ratio of forward to backward emission as a function

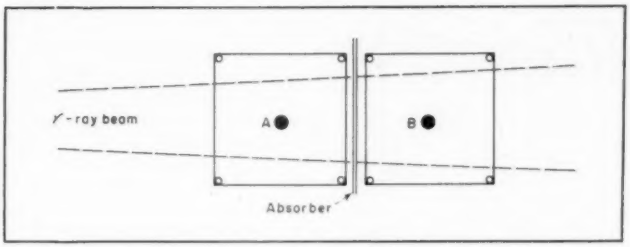


FIG. 3. Arrangement of ionization chambers (A and B) and absorber

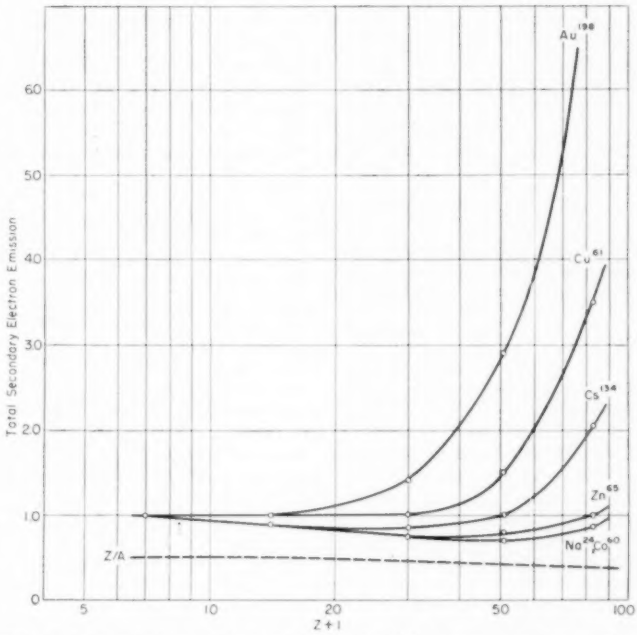


FIG. 4. Total secondary electron emission produced by gamma rays from various nuclides as a function of $\log(Z+1)$ of the absorber

of the atomic number of the absorber and the γ-ray energy has been discussed recently (*8*).

The results obtained with an ionization chamber for the forward emission of secondary electrons produced by the Co^{60} γ-rays in various materials could be verified with an end-window Geiger-Müller counter. A very well collimated γ-ray beam was incident on a 3-mg/cm^2 mica window so that no primary γ-rays struck the counter cathode. The counting rate obtained under these conditions was regarded as "background." A carbon absorber placed in front of the counter window increased the counting rate by a factor of seven, while tin was only half as effective. These results are in perfect agreement with those obtained from the ionization-chamber measurements. A counter registers the number of incident electrons, while the ionization-chamber current is proportional to the number of electrons times the fraction of their energy that is absorbed in the chamber. Since the range of the secondary electrons in air is large in comparison with the chamber dimensions, the results are independent of

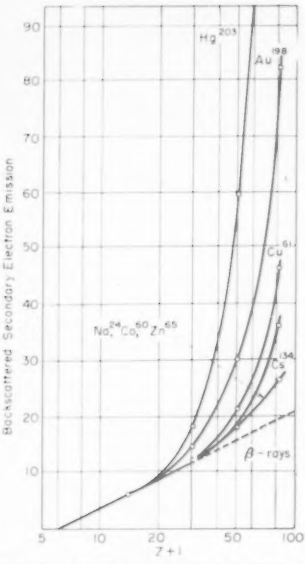


FIG. 5. Backscattered secondary electron emission produced by gamma rays from various nuclides as a function of log (Z + 1) of the absorber

the energy distribution of the secondary electrons.

We will confine ourselves to the so-called "incident" secondary electron emission. For the following reasons, however, we will refer to it as "backscattered" emission.

Secondary electrons produced by high-energy γ-rays are always emitted within a rather narrow cone having the initial direction of the γ-ray as axis (9). Even Compton electrons and photoelectrons, which originate from γ-rays with energies of 0.5 Mev, or less, are emitted predominantly in the forward direction. Therefore, if electron scattering did not change the original secondary electron distribution, all electrons would leave the absorber through its front surface. This is in agreement with the observations made with carbon absorbers (8), where the forward emission is at least 10 to 20 times the backward emission for all γ-ray energies.

The saturation backscattering of β-rays has been measured by various authors whose results are in agreement with each other (10, 11). A β-ray source mounted on a very thin foil is placed at some distance from an end-window counter. The β-rays leaving the source in a direction opposite to the G-M counter have no chance of being counted. When a thick layer of material is placed behind the source, a certain fraction of the β-rays originally lost is now scattered backwards and is detected by the counter. This fraction has been found to increase linearly with $\log(Z + 1)$ of the backscattering material, independent of the β-ray energy (11).

Since the secondary electrons produced by γ-rays are mainly emitted in the forward direction, they can be expected to be backscattered within the medium in a way similar to that of the electrons from a β-ray source under the above conditions. The results obtained with the radium γ-rays have been shown in Fig. 2, those with the radionuclides listed in Table 1 are given in Fig. 5. For the high-energy γ-rays, the intensity of backscattered secondary electron emission increases linearly with $\log(Z + 1)$, up to about $Z = 40$. This is in agreement with the above assumptions. For materials of higher atomic numbers, the total emission of secondary electrons increases because of the production of photoelectrons. Therefore, the intensity of backscattered secondary electrons increases more rapidly than that of β-rays, for high-Z materials and low-energy γ-rays. The backscattering from carbon is so small that no accurate values could be obtained. The results with the various γ-ray sources given in Fig. 5 are therefore adjusted to the same intensity value for the backscattering with aluminum absorbers.

The reason why, for radium γ-rays, the secondary electron emission in the forward direction (Fig. 1) decreases with $\log(Z + 1)$ up to $Z \sim 40$ is now obvious. The total secondary electron emission from high-energy γ-rays (Fig. 4) is about constant up to $Z \sim 40$. The backscattering of electrons increases with $\log(Z + 1)$, and therefore the emission in the forward direction has to decrease accordingly.

From the above results it follows that for a given γ-ray source the backward emission of secondary electrons is only a function of the atomic number of the absorbing material. Therefore an "effective" atomic number of a material of unknown composition can be determined from its backscattering ability.

The saturation backscattering from various materials is independent of their densities. The production of Compton electrons per cm^3 of a medium is proportional to the number of electrons present in the medium, that is, it is proportional to $\rho \times NZ/A$. The range of electrons in a low-atomic-number material is inversely proportional to its density, ρ. Therefore, the secondary electron emission is independent of ρ, and no absorption corrections for the primary or secondary radiation have to be applied for the backward emission from different materials.

Effective Atomic Numbers

The absorption of γ-rays of known energy in a certain material cannot be predicted if only the density of the material is known. The interaction of γ-rays with matter depends also on the atomic number, Z, of the absorber (12). For a γ-ray of given energy, the probability of absorption (per gram of absorber) by photoelectric effect varies as $(N/A)Z^{4\text{-}5}$ of the absorber, where N is Avogadro's number and A is the atomic weight of the material. The production of Compton electrons is proportional to the number of electrons per gram, that is, $(N/A)Z$. Finally, for high-energy photons, the pair-production absorption coefficient (per gram of absorber) is proportional to $(N/A)Z^2$. Therefore, it is important to know the atomic number of an absorber. However, for several materials, such as concrete, plastics, or bones, which are frequently exposed to γ-rays, the exact chemical composition is unknown.

Since each of the three γ-ray absorption processes varies with a different power of Z, it is obvious that for a material composed of several elements there exists also a different "effective" atomic number for each absorption process. Some formulas will be derived from which the effective atomic numbers for a material of known composition can be calculated.

The absorption of X- or γ-radiation is given by

$$I = I_0 e^{-\mu x} = I_0 e^{-(\mu/\rho)m} \qquad (1)$$

where I_0 is the initial radiation intensity, and I is the intensity of the primary beam after passing through an absorber of thickness x (cm), or m (gm/cm^2). The linear absorption coefficient, μ, is a function of the radiation

energy and the absorbing material; μ/ρ is the so-called mass absorption coefficient (cm^2/gm).

If the absorber is composed of various elements, the percentage by weight of each element in the material is given by p_i so that

$$p_i m = m_i \quad \text{and} \quad \sum_i p_i = 1 \qquad (2)$$

The coefficient of the exponential in Eq. 1 then becomes

$$\left(\frac{\mu}{\rho}\right) m = \sum_i \frac{\mu_i}{\rho_i} m_i = m \sum_i \frac{\mu_i}{\rho_i} p_i$$

$$\frac{\mu}{\rho} = \sum_i \frac{\mu_i}{\rho_i} p_i \qquad (3)$$

Considering the different types of absorption processes, the photoelectric, τ, the Compton, σ, and pair production, κ. Eq. 3 can be written as

$$\frac{\mu}{\rho} = \frac{\tau}{\rho} + \frac{\sigma}{\rho} + \frac{\kappa}{\rho} \qquad (4)$$

As mentioned above, the absorption coefficients τ, σ, and κ are functions of the radiation energy, the atomic number, Z, and the atomic weight, A, of the absorbing material (*12*). They can be expressed as follows

$$\frac{\tau}{\rho} = k_1 N \left(\frac{Z^{4.1}}{A}\right) f_1(h\nu)$$

$$= k_1 N f_1(h\nu) \sum_i p_i \frac{Z_i^{4.1}}{A_i} \qquad (5)$$

$$\frac{\sigma}{\rho} = N \left(\frac{Z}{A}\right) f_2(h\nu)$$

$$= N f_2(h\nu) \sum_i p_i \frac{Z_i}{A_i} \qquad (6)$$

$$\frac{\kappa}{\rho} = k_3 N \left(\frac{Z^2}{A}\right) f_3(h\nu)$$

$$= k_3 N f_3(h\nu) \sum_i p_i \frac{Z_i^2}{A_i} \qquad (7)$$

Finally, Eqs. 4–7 together result in

$$\frac{\mu}{\rho} = N \sum_i \frac{p_i}{A_i} [k_1 Z_i^{4.1} f_1(h\nu) + Z_i f_2(h\nu) + k_3 Z_i^2 f_3(h\nu)] \qquad (8)$$

As a first approximation, Z/A can be regarded as constant for all elements* (Fig. 4). Therefore, the following equation is also a fairly accurate one

$$\frac{\mu}{\rho} = N \frac{Z}{A} \sum_i p_i [k_1 Z_i^{3.1} f_1(h\nu) + f_2(h\nu) + k_3 Z_i f_3(h\nu)] \qquad (9)$$

From Eq. 9 it can be seen that the absorption by Compton effect is the same for all materials, and depends only on $f_2(h\nu)$. For the absorption by the photoelectric process, an effective atomic number can be defined as

$$\bar{Z}_{\text{photo}} = \sqrt[3.1]{\sum_i p_i Z_i^{3.1}} \qquad (10)$$

so that $\bar{Z}$ represents the atomic number of the composed material. Spiers (*13*) gives the correct formula which includes the variation of Z/A from low- to high-Z elements. However, since we will concern ourselves only with low-Z material, the simplified Eq. 10 gives the same results. Spiers uses 3.94 instead of 4.1 as the power of Z for the photoelectric absorption. More recent measurements favor the somewhat higher value.

For very-high-energy radiation which is produced by a betatron or other accelerator, absorption by pair production becomes predominant. From Eq. 9 an effective atomic number of a material for the absorption of γ-rays by pair production can be defined as

$$\bar{Z}_{\text{pair}} = \sum_i p_i Z_i \qquad (11)$$

Comparison of Eqs. 10 and 11 shows that $\bar{Z}_{\text{pair}}$ will be always smaller than $\bar{Z}_{\text{photo}}$. If the percentage weight of some components is small, the difference between the two will be also small. For example, the two effective atomic numbers for water and calcium carbonate are

H_2O: $\bar{Z}_{\text{photo}} = 7.44$; $\bar{Z}_{\text{pair}} = 6.60$

$CaCO_3$: $\bar{Z}_{\text{photo}} = 15.24$; $\bar{Z}_{\text{pair}} = 12.56$

At the end of the preceding section it was stated that the emission of backscattered secondary electrons increases as $\log(Z + 1)$ of the material up to $Z = 40$ for high-energy γ-rays. The intensity of backscattered secondary electrons can therefore be expressed by

$$I = k_4 \log(Z + 1) \qquad (12)$$

For a material composed of various elements, Eq. 12 may, as a first approximation, be written

$$I = k_4 \sum_i p_i \log(Z_i + 1) = k_4 \sum_i \log(Z_i + 1)^{p_i} \qquad (13)$$

where p_i is again the percentage weight of each element. From Eqs. 12 and 13 an effective atomic number can be defined for the backwards emission of secondary electrons from a composite material as follows

$$\log(\bar{Z}_{\text{back}} + 1) = \log \prod_i (Z_i + 1)^{p_i}$$

$$\text{or} \quad Z_{\text{back}} = \prod_i (Z_i + 1)^{p_i} - 1 \qquad (14)$$

With the same examples as above, the effective atomic numbers will now be

H_2O: $\bar{Z}_{\text{back}} = 5.7$

$CaCO_3$: $\bar{Z}_{\text{back}} = 11.2$

These values appear to be the smallest of the effective atomic numbers discussed here for the different processes of γ-ray absorption and backscattered secondary electron emission. It can be shown generally that $\bar{Z}_{\text{back}} < \bar{Z}_{\text{pair}}$; this means that

$$\prod_i (Z_i + 1)^{p_i} - 1 < \sum_i p_i Z_i$$

$$\text{or} \quad \prod_i (Z_i + 1)^{p_i} < 1 + \sum_i p_i (Z_i + 1) - \sum_i p_i \qquad (15)$$

Since $\sum_i p_i = 1$, Eq. 15 becomes

$$\prod_i (Z_i + 1)^{p_i} < \sum_i p_i (Z_i + 1) \qquad (16)$$

This inequality is known as the theorem of the arithmetic and geometric means (*14*).

In the following section a method will be described which allows one to determine $\bar{Z}_{\text{back}}$ experimentally in a rather simple way for materials of unknown composition.

Effective Atomic Numbers of Bone

Bone has been chosen as a composite material for which $\bar{Z}_{\text{back}}$ is to be determined for the following reason. The unit for the radiation dosage applied in radiotherapy or otherwise is the roentgen. This ionization unit refers to a fixed amount of radiation energy absorbed per gram of air, independent

* Hydrogen, for which $Z/A = 1$, is the only exception. In this case p_i has to be replaced by a_i, where a_i is the fractional content of electrons belonging to the atomic number Z_i (*13*).

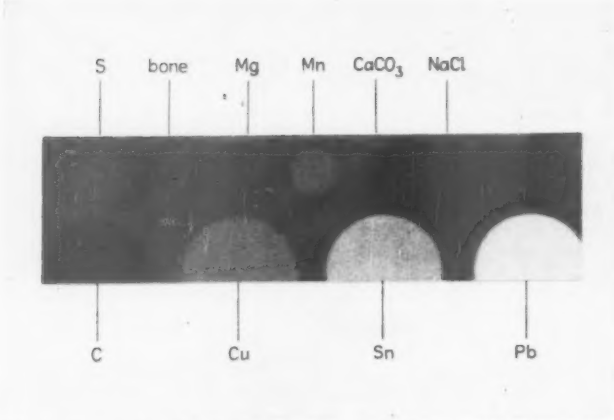


FIG. 6. Film negative of the backscattered secondary electron emission from various materials irradiated by cobalt-60 gamma rays

of the wavelength of the incident radiation. However, for any medium which has a different atomic composition than air, the energy absorption depends on the electron density of the medium and its effective atomic number.

Body tissues, like muscle, have an atomic composition rather similar to that of air. Therefore, the energy absorption in ergs per roentgen in tissue is nearly constant, independent of the wavelength of the incident radiation (*13, 15*). For bones, however, which contain large amounts of calcium and phosphorus, this is not true. To evaluate the radiation dosage received by bone from various types of radiations, it is important to know its effective atomic numbers.

Uniform layers of bone powder and a flat bone section have been used by Spiers (*13*) for the determination of the mass absorption coefficient, μ/ρ. Since these absorption measurements are made with monochromatic X-rays with energies below 30 kev, photoelectric absorption is predominant. The resulting effective atomic number of bone is $\bar{Z}_{photo} = 13.8$.

These measurements have been extended by Spiers to other media. His results are given in Table 2 together with the corresponding values for n_0, the number of electrons per gram of medium, and the density, ρ.

The number of electrons per gram appears to be greater for the aqueous tissue, compared with air and dry bone which contain no hydrogen. This derives from the fact that Z/A of hydrogen is one, while for all other elements up to calcium $Z/A \sim 0.5$. Therefore, the energy absorption per gram of medium by the Compton process will be about 10% larger in muscles and fat compared with that in air or bones.

To our knowledge no measurements have been made so far to determine experimentally the effective atomic number of bone for pair production. The values for $\bar{Z}_{pair}$, given in the last column of Table 2, are taken from Johns (*15*) who has calculated them according to Eq. 11. The experiments to be described here allow an evaluation of $\bar{Z}_{back}$ which is somewhat smaller than $\bar{Z}_{pair}$.

The relative intensity of secondary electrons backscattered from various media can be detected with an ionization chamber as described above. The size of homogeneous bone material available for the back wall limits the dimensions of the chamber. Wilson (*2*) has performed such measurements with radium γ-rays and has obtained for the effective atomic number of bone, $\bar{Z}_{back} \sim 12$.

Instead of an ionization chamber, photographic film can be used as a radiation detector with the following precautions. The density of the exposed and developed film is proportional to the radiation intensity only if the energy of the primary γ-rays is greater than about 500 kev. Otherwise, the direct interaction of the γ-rays with the photographic emulsion changes rapidly with the radiation energy. Furthermore, the range of the secondary electrons, emitted from the materials (cassette, absorbers, air) which cover the photographic emulsion, has to be large in comparison with the emulsion thickness. Rather-high-energy electrons, the ion density of which does not vary much with their energy, have to penetrate the emulsion and also part of the adjacent materials. Finally, the angular distribution of the secondary electrons, emitted from different materials, has to be approximately the same. This also holds for high-energy primary radiation.

For X-rays generated at 200 kv, filtered by 2 mm Cu + 1 mm Al, the above conditions will not be satisfied. Therefore, the results obtained by Wilson (*16*) with this type of radiation are not conclusive. They show large variations of the backscattered intensity from different elements and materials which cannot be correlated with their effective atomic numbers. If, instead of X-rays, the high-energy Co^{60} γ-rays (Table 1) are employed, more consistent results can be expected.

TABLE 2 Effective Atomic Numbers of Various Materials

Medium	n_0 (gm^{-1})	ρ (gm/cm^3)	$\bar{Z}_{photo}$	$\bar{Z}_{pair}$
Air	3.03×10^{23}	0.00129	7.7	7.4
Water	3.34×10^{23}	1.0	7.4	6.6
Muscle	3.36×10^{23}	1.0	7.4	6.6
Fat	3.48×10^{23}	0.9	5.9	5.2
Bone (dry)	3.0×10^{23}	1.9	13.8	>11.5
Bone (wet)				10.0

Furthermore, the double-coated type-A film, which shows a linear relation between dose and film density up to densities of about three (*17, 18*), can be used.

The bone used for the determination of backward emission of secondary electrons is a solid piece from a human femur, carefully cleaned by extraction with ethylene diamine. It is mounted with some wax in a hole of a thick block of aluminum and ground flat with the surface of the block. Besides the bone, nine different materials of known composition are mounted in other holes of the aluminum block. The film, placed in close contact with the top surface, is covered by ¼ in. of Masonite sheet. A 5-mc Co^{60} source, which consists of a thin cobalt wire about 5 mm long, is placed at such a distance (1 meter) from the aluminum surface that the intensity is constant over the whole surface area.

The results obtained under the above condition for the saturation backscattering are shown in Figs. 6 and 7. Figure 6 is a negative print of the original film, and the greatest film density, obtained with the lead, appears white. With the exception of manganese, the materials in the upper row all show a density very close to that of aluminum; therefore they might not show up very well in the reproduction. The wax which surrounds the bone appears darker than the bone itself.

The film densities obtained from two different exposures are plotted in Fig. 7 as a function of $\log(Z+1)$ of the materials. In agreement with the ionization-chamber measurements, the relative intensity of secondary electrons backscattered from different elements increases linearly with $\log(Z+1)$ from carbon to copper. The emission of photoelectrons by tin and lead, in addition to the Compton recoil electrons, causes again a deviation for the high-Z elements. For $CaCO_3$ and NaCl, the effective atomic numbers for backscattering have been calculated according to Eq. 14. They are

$$CaCO_3: \quad \bar{Z}_{back} = 11.2$$
$$NaCl: \quad \bar{Z}_{back} = 14.3$$

The observed densities of these two compounds plotted at the above values fit well on the curve determined with pure elements. Variations of the emulsion thickness limit the accuracy of the film measurements to about 5%.

Finally, the density values observed with the bone allow an estimate of its effective atomic number for the backscattering of secondary electrons. The average value obtained from a great number of measurements is $\bar{Z}_{back} = 11.5 \pm 0.5$. This value is in good agreement with the one obtained by Wilson (*2*) by means of ionization-chamber measurements. If, instead of the Co^{60} γ-rays, the softer γ-rays from Au^{198} or Hg^{203} (Table 1) are employed, the observed density values no longer fit on a smooth curve. This is to be expected since the above stated conditions for the detection of electrons by means of film are not satisfied by using γ-rays with energies less than about 500 kev.

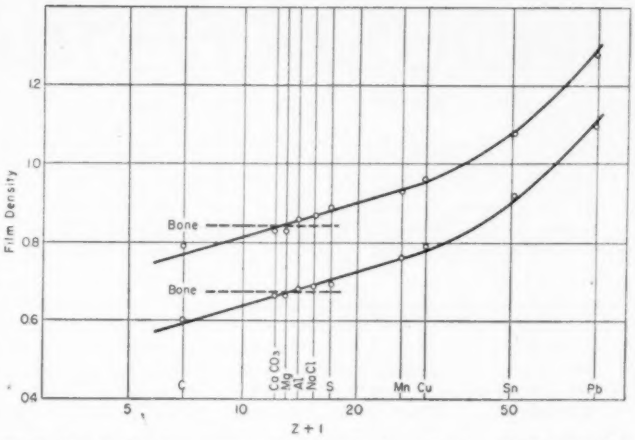


FIG. 7. Film densities from exposure like that in Fig. 6 as a function of $\log(Z+1)$ of the backscatterer

For dry bone, the effective atomic number for pair production has to be greater than the one determined for the backscattering of secondary electrons. Therefore, $\bar{Z}_{pair} > 11.5$ has been included in Table 2. For wet bone, containing 25% water and 25% organic matter, Johns (*15*) has calculated that $\bar{Z}_{pair} = 10.0$.

* * *

The author wishes to thank Professor R. D. Evans for his valuable criticism and many suggestions

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INDUSTRY . . . the ATOM

Because of secrecy regulations, the phases of our atomic-energy program which are absorbing the greatest expenditures are those about which the least is known. There are very few people in this country who have anything resembling an over-all picture of the details of the program. In part because of the secrecy and in part because of the newness of this technology, there has been an aura of mystery surrounding the field.

Within the past six weeks, two excellent talks were given by AEC Commissioners Dean and Glennan. Both aimed their remarks at industry and stressed the importance of having more companies find out "what's in it for me" as far as atomic energy is concerned. Because this reflects a growing attitude within the AEC, the portions of these talks reproduced on the following pages take on special interest.

In addition to the ignorance of the present program in many quarters, no one has a clear picture of what the future is for nuclear power. The remarks of Messrs. Dean and Glennan should help fill in some on the present program. To shed further light on the question of nuclear power, we are publishing on pages 21–23 extracts from a recent talk by Sir John Cockcroft, director of the British Atomic Energy Research Establishment and recent winner of the Nobel Prize for physics. Sir John discusses some problems in reactor technology and what the British are doing about them. —*The Editors*

An Invitation to Industry

By T. KEITH GLENNAN*
Member, U. S. Atomic Energy Commission
Washington, D. C.

THE BASIC operating principle of the AEC is to accomplish its production goals through the genius of American industry. As the engineer assumes an increasingly important role in the leadership of both industry and the atomic-energy program, it seems worthwhile to discuss some aspects of the present and future role of industry and business in this great new activity. My own concern about the overlong continuation of the present governmentally dominated industrial-governmental relationship for the prosecution of the atomic program makes this opportunity for discussion attractive to me.

Perhaps we can best get into this by asking some questions and then suggesting answers that may stimulate further study and debate on this subject. Some appropriate questions, I would say, would be:

1. How did the AEC get its present contractors?
2. What are the handicaps of working in the atomic program?
3. What are the incentives?
4. What is the AEC doing to help industry and management to understand the atom business?
5. What should be the role of private industrial enterprise in the future of a rapidly growing government enterprise—an enterprise which takes on many of the aspects of a monopoly created by law—an enterprise upon which much of the future security and well being of this nation may substantially depend?

Most of the distinguished names in American industry are to be found on the roster of prime contractors of the AEC. [There are] 500 major contractors. As a group, these firms make up a substantial segment of the top industrial organizations in America. And more companies are coming in as the program expands. How, then, did these firms get into this business and why are they working for the government?

I would not presume to try to answer for each of these industrial contractors. However, I have made it a point to raise the question with several of those who have been in it for a long period of time; and to raise the question also with the General Manager [of AEC], the operating managers at the field offices, and with the directors of program divisions at headquarters. It is important to have the answers to this question, for there is every evidence that the dedication of the managerial skill, the operating competence, and the cost-cutting know-how of industrial contractors large and small has played a major part in making this nation's atomic program as successful as it has been. If the atom business is to thrive and prosper on a prospectively broader scale, the nation must command more rather than less of such dedication and service on the part of industry.

In brief, the responses to my inquiries have indicated that two motives have dominated the decisions of industrial management to accept the uncertainties of Federal service in the atomic-energy program—and both of these motives continue to satisfy the newcomer to the business today. The first was expressed rather well by Dr. George Felbeck of Union Carbon and Carbide when he said: "Why take one of these government jobs and after you have it, why stay with it? Corporations as we know them are creations of the American system, and they exist and flourish because of that system. If we lose a war, we know the system will change and that corporations will cease to exist. It is simply a question of survival. The men in Government are devoting their lives to the preservation of the environment in which we can do business. There is no privilege reserved to corporations or corporation employees which allows them to shirk their duties of citizenship. It is the duty of every corporation to make those contributions to the defense of this country which it is qualified to make."

* From a talk before American Society of Mechanical Engineers, Atlantic City, N. J., Nov. 29, 1951.

and NUCLEAR POWER

The second motive has arisen out of the feeling that it is prudent and forehanded to become conversant with and facile in this new technology and science which may influence so widely the future course of engineering and production. But more of this later—let's look at some of the handicaps or deterrents to industrial participation in this type of governmental-industrial relationship.

First, and most obvious, is the fact that the atom business is a government-owned operation. . . . This is hardly the kind of an atmosphere that would sound attractive to private enterprise. This was particularly true back in 1947 when industry had the pleasant prospect of satisfying the pent-up demand for the billions and billions worth of civilian goods denied a high-earning, large-saving American population during six years of war and reconversion.

The fact that the atomic-energy program is a governmental monopoly means that—for industry—the *normal* profit incentive is lacking. For the same amount of talent and effort put into its own business, any industrial concern would expect to earn profits, even after taxes, far in excess of the fees allowed under an AEC contract. It must be remembered, of course, that industry makes little or no financial investment in the atom business and takes no very great risk of substantial financial loss. Nevertheless, a very real investment is exacted of the contractor in terms of the qualified men required to be assigned to the job. Top technical and management brains are necessary even though they must be diverted from other work. Taking these facts into account and recognizing its obligation to the taxpayer, the AEC sets the fees paid for management services at the lowest figure that can be negotiated. Under the conditions that have existed to date this system has seemed about as fair as any that could be devised. Nevertheless, the normal (and I emphasize *normal*) profit incentive is lacking.

A second deterrent to private participation is the patent situation. Under the Atomic Energy Act, inventions and discoveries made in connection with the work become restricted data if connected with fissionable material for weapons, or become public property available for nonexclusive licensing if they are nonmilitary and declassified.

There appear to be two viewpoints on this particular problem. One group feels that if normal patent incentives were restored throughout the atomic field, private money would flow in and development would go forward in a manner more businesslike, faster and cheaper. Equipment and processes developed in the atom business would be available for use in the contractor's regular business. There are some who see in the patent clauses of the Atomic Energy Act an attack on the patent system generally.

Opposing this view is the one that suggests that there has been little possibility of private industry making much of an investment in the atom on a risk basis. The price tag has been high and the market extremely limited and uncertain. Weapons uses seem inevitably to dominate the field in the foreseeable future. This second viewpoint holds that, when the time arrives for commercialization of some aspects of the atom business, everyone will be on even terms. There will be no special legal or economic privileges deriving from patent advantages held by the insiders—the AEC contractors. You will have to take your choice, but remember that public money is involved.

Security is Handicap

A third handicap is the vital security regulations that must be added to the usual problem of government red tape. This causes exasperating delays in building up staffs of personnel who must be cleared after time-consuming background investigations. It requires the expenditure of millions of public dollars that must appear wasteful to the average hard-headed industrialist, until he has been educated on the importance of security. On the red-tape side—well—need one say more about this? And yet much of it is necessary in the interest of accounting to the taxpayer even as large industry tends to become a victim of its own red tape in the interest of accounting to the stockholders or the trustees.

There is also the fact that health and safety standards are much more rigid in atomic work than in normal industrial operations. To an outsider not familiar with the scope of radiation hazards, the AEC precautions may seem unrealistic. Potentially, the atom business is one of the most dangerous in the world. In practice, it is one of the safest. But the time-consuming precautions require men and may make a potential contractor hesitate before committing his firm to an AEC contract.

Given the lack of normal profits, the absence of patent protection, the unusual expense in terms of manpower, the complex security regulations, unusual health standards and a fair supply of red tape, one might well ask why private enterprise hasn't pulled out of the atom business entirely and let Uncle Sam run it as best he could with government employees. This had been proposed by certain groups in this country. We in the AEC feel that any approximation of such a course would be a national calamity. And we believe that there are reasons why this has not happened.

Those contractors who shared the load during the war acted without hesitation under the most impelling of motives—a patriotic sense of duty to the nation. But they could have withdrawn at the end of the war. A few did but most of them are still in the program. Here are some reasons for their action in continuing—reasons which I repeat, I have heard from the men who head the larger of our contracting companies.

Prestige might be put near the top of any list of incentives. It is sometimes difficult for critics of the capitalist system to believe that the industrialist has any interest other than profits. You and I know that pride of achievement is one of the driving forces that has made this country the greatest industrial nation in history.

When the war ended within a fortnight after atom bombs fell on Hiroshima and Nagasaki, there was glory for all who had a part in the magnificent gamble. Since then the record of the AEC in achievement, in my judgment, has been good. People, by and large, think that the progress in atomic weap-

Need for a Progressive Outlook

On November 25, the subject for discussion at the University of Chicago Roundtable was "Atomic Weapons and Defense." Drs. Joseph E. Mayer, Frederick Seitz and Harold C. Urey analyzed the implications of Senator Brien McMahon's recommendation that our atomic budget be increased by $5-billion. Presented below, with the permission of the University of Chicago, are several excerpts from the discussion.

Dr. Seitz: I have a feeling that the Atomic Energy Commission should take funds which are voted through the channels which Senator McMahon would provide and spend at least part of them in tyring to spark entirely new developments. It is quite remarkable and noteworthy that at the start of the last war, when our economy was under its greatest stress, we were willing to take a chance on something which probably had a very small probability of paying off. But we did this in 1940, and as a result we have atomic weapons. It seems to me that there is a great danger that an organization such as the Atomic Energy Commission, which is doing a wonderful job of production, will lose sight of the fact that it must learn to take a chance on certain kinds of new developments.

Dr. Urey: I myself feel that there has been a lack of enthusiasm for the development of useful atomic power. I spent some time at Oak Ridge last summer myself, working on this problem. It is a difficult problem; but it does not ook impossible to me that useful atomic power can be secured. And I returned to Chicago to find prominent members of the [AEC General] Scientific Advisory Committee advising the public that all this sort of effort is not of much value. Dr. James B. Conant made a speech in New York, saying that by 1960 we would all drop the development of atomic power as something which was not worth a candle; and Dr. Lee Du Bridge of the California Institute of Technology says that it will be thirty years before atomic power can be developed. Other members of this Scientific Advisory Committee say that the development of atomic power is not worth while. All these things remind me of the fact that this committee was not the one to push the development of the H-bomb. I believe that there has been a lack of enthusiasm by people who are advising the government on this subject which is wholly unjustified, and it might be well if such a position were revised in the future. . . .

Dr. Urey: The propaganda value to Russia of getting peacetime atomic power would be very great providing it was secured by the Russians first. I think that it might be very worth while if we kept pushing away on this subject of peacetime atomic energy. Of course, getting peacetime atomic-energy plants is one of the best ways to explore some of the possibilities which Senator McMahon has in mind, namely, putting power plants on ships. He does not mention putting them on airplanes, and I think that this is not a very promising use. But this problem of securing power is something that we should not allow to fall to the Russians by default.

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ons under the management of the AEC has constituted a significant contribution to national security and the preservation of a degree of world peace. This has meant good will and prestige for those industries that have made this progress possible. I believe this factor is most persuasive in encouraging other segments of industry to come into the program.

Another tangible asset is the improvement in technical resources and staff that comes with participation. This is the other side of the coin which complains about diversion of top men from a contractor's regular private business. The atom industry is still a challenge; it retains the air of—and it is indeed—an adventure; it appeals to young minds despite the distasteful aspects of some elements of the security restrictions. AEC contractors thus have a decided advantage in building up more competent technical staffs.

The AEC supports a policy of trying out new processes, new equipment, new gadgets. We are still young enough to be unorthodox when such a course seems to promise progress or cut costs. This appeals to the good engineer. He is called the "enemy of error" and at many stages of our work, trial and error is the only method of solving a complex problem. All these factors make the atom business appealing to many industrial leaders and can result in adding great strength to any organization.

Finally, there is the idea of "getting in on the ground floor," which I mentioned earlier. No industrialist knows just what the atom will mean to him. But he doesn't want to be left behind when the parade starts. Admittedly, the parade hasn't started yet, but from time to time, one catches the distant rumble of the processional drums. There are enough new things being done in chemistry, metallurgy, electronics and a dozen other areas of this business to make this desire to be in on the ground floor a powerful factor in attracting new blood to the program.

I think it is fair to put it in the record at this point that the AEC has taken a number of steps to make things as attractive as possible to private enterprise. The over-all government ownership and control is a matter of law. Continuation and expansion of the contract system has been a matter of policy. The agency has limited the role of the government largely to policy, security, standards of performance and contract administration.

Let's take a look at the future and some of the problems of opening the door for private investment, risk-taking, and profit-making in atomic energy.

In its latest annual [atomic energy] roundup, *Business Week* said: "As recently as a year ago, you had to look hard and long to find serious interest among businessmen in atomic matters. To most of them this was something for the military, the scientists and the government to worry about. More than once, the AEC people have had

to beat on the desks and make patriotic appeals in order to find companies willing to take on projects for it.

"Today, you can see signs of a rush to get into the field before the ground floor gets too crowded. Many companies are coming to AEC asking for assignments, and it needs only a hint of government receptiveness to bring in more.

"For the first time, businesses are spending a little of their own money to get a toehold in the area. Several are thinking about large investments."

This was, by and large, an accurate report, and there are two obvious reasons for the change in climate. First, the atom business is getting so big that it involves almost every kind of industry at some point or other. Second, as we continue to make significant strides toward the production of useful power for the propulsion of military vehicles, the prospect of central-station power from atomic fuels, and other peacetime uses, becomes more exciting.

If I have one message it is this—don't sit back and wait for things to happen in the atom business. Continue to be impatient about the future and the enlargement of industrial participation on a basis that will allow your companies to earn a return on your efforts commensurate with the risk they will take. And look for the opportunities to take that risk. If you do not do this it is my opinion that you may well be witnessing the first step in the extension of governmental control over our basic industries.

There should be no misunderstanding, however, about this one point. The law charges the Commission to develop the use of the atom for the benefit of the nation and mankind subject at all times to the paramount objective of promoting our common defense and security. Today this means getting on with the weapons business. This grim job we are doing and doing with a grim will. You know, however, that the process of manufacturing fissionable material is the same whether the material is to be shaped into parts of weapons or into fuel assemblies for peacetime uses. The present international situation requires that the government continue to own and control the source materials and the finished product. Should the efforts of this and the other free nations to obtain an effective system of international control and disarmament succeed, it would appear possible and desirable to release into normal competitive channels these materials which hold such promise for the future.

Until that time arrives it is the duty and responsibility of each of us to learn as much as possible about current technology in the atom business. How else will you be able to enter the field when and as the opportunity presents itself?

What I would like to see is more industries knocking at our door and asking "what's in this for me" and being prepared to lay money on the line to find out.

As more companies get a dollar stake in the atom business, we will have a more critical examination of the assets and liabilities of the business. This is essential if we are to get intelligent and workable answers to the questions that we will face in the future—the questions of how the military and the general civilian applications of atomic energy shall be operated and industrially developed—whether by government monopoly or by private enterprise or by a mixture of the two.

Unless this is done the likely thing will be that atomic-energy development and operations, in the absence of any desire, any demonstration of the capabilities of private enterprise in this field, will by default continue as a government monopoly and become more rather than less of a straight government operation.

A Factual Look at Our Atomic-Energy Program*

By GORDON DEAN*
Chairman
U. S. Atomic Energy Commission
Washington, D. C.

WHERE DOES the atomic-energy program fit into the mobilization picture? Dollarwise, it does not amount to very much. Of the $100-billion appropriated for the procurement of hard goods and construction since Korea, for example, only about $2-billion has been earmarked for similar expenditures for the atomic-energy enterprise. The bulk of this is being spent on a substantial expansion program.

Actually, this is the Atomic Energy Commission's second major expansion effort. The first one, consisting of projects begun in 1949, involved mainly a $300-million expansion in the productive capacity of the Hanford plutonium plant, and a $220-million expansion in the productive capacity of the Oak Ridge uranium separation plant. The main ingredients of the current program—the second—are a huge new plant at Aiken, South Carolina, which eventually will cost more than $1¼ billion, and a new $500-million plant at Paducah, Kentucky.

And now, the AEC and the Department of Defense are currently working on the development of plans for still another expansion of our atomic-energy productive capacity.

At first glance, one might assume that this should not be too much of a problem. After all, it might be said, $2-billion out of $100-billion is not, relatively speaking, too large a sum, and there would appear, on the surface, to be every reason to believe that a few more billions or so for something as important as atomic-energy facilities should be money well spent.

But unfortunately it is not as simple as that, for there are a good many factors besides dollars which help determine the over-all size of the program. To name a few:

1. The uranium supply. No matter how strongly we might desire to increase our capacity to produce atomic-energy materials, we are fundamentally limited in the size of our program by the supply of accessible uranium.

2. The state of the art. The military services determine the types of atomic weapons they need and indicate the quantities they need, and in these determinations they are quite naturally limited by the status of atomic weapons technology at any given time.

3. The effect on the economy. Although the amounts of money we deal

* From a talk before American Ordnance Association, New York, N. Y., Dec. 5, 1951.

in are a relatively small percentage of total defense expenditures, we have a disproportionately large demand for many items that are in critically short supply, including certain categories of both materials and manpower.

Future Expansion

Viewed in the light of these determining factors, there are two principal reasons why a further expansion of the atomic-energy program is being considered at this time:

First, there has recently been a very decided improvement in the uranium supply outlook. Although the known sources of uranium available to us today are certainly far from inexhaustible, they nevertheless do represent a substantial improvement over the situation which prevailed until a relatively short while ago.

There are a number of factors which have contributed to this improvement, and among them we might list: (1) the discovery of new uranium deposits in Canada, (2) the extension through an intensive exploration program of the uranium-bearing region of the United States' Colorado Plateau, (3) the development of improved and more economical methods for extracting uranium from lower-grade ores, and (4) the conclusion of an agreement whereby the United States and Great Britain have been given access to the very large stores of uranium which occur as a minor constituent in the residues of gold production in the Union of South Africa.

The second principal reason why a further expansion of the atomic-energy program is now being considered is the fact that recent technological developments have taken place which have made possible the consideration of atomic weapons for tactical as well as strategic employment.

Materials, Power, and Men

The above is what we might call the positive side of the expansion picture. But there is a negative side, too, and we begin to become aware of it when we look into the impact on the economy of a further expansion of the atomic-energy enterprise. As I mentioned before, the atomic-energy program, although relatively small dollarwise, has a disproportionately large demand for many items that are in critically short supply. As an example, I might cite nickel. The current construction program of the AEC is consuming something over 7% of all the nickel produced in this country, and this rate of consumption will be increased next year even if no further expansion is undertaken.

Or, we might take sulfur, which, in contrast to nickel, is a continuing operational requirement of the atomic-energy program. The atomic-energy program is today consuming around 5% of our total national production of sulfur, and will steadily increase this demand.

These are not the only examples. There are many more, and some of them are particularly impressive. In this category we could certainly include stainless steel tubing, which our current construction and operating programs are consuming at a rate equal to about one-half of the total annual national production and the peak of our demand has not yet been reached.

Our demand for structural steel on the other hand, is rather small in comparison with the total supply. Of the 1,450,000 tons to be allotted during the first quarter of 1952—which, incidentally, is only half of the total national demand—only 36,500 tons constitute requirements of the AEC.

So far, I have been talking about materials. Now let's look at power. The atomic-energy program is consuming power at a rate which by next June will be comparable to that of New York City, or roughly 2% of the total national supply, and this demand will increase enormously as additional new plants now under construction begin to come in. For example, our new uranium separation plant now being built at Paducah, Kentucky, will have a power demand of about 1 million kw.

It is true that the power capacity of the United States is now being expanded as part of the nation's industrial mobilization program, and that, through these efforts, new generating capacity of nearly 7 million kw will be added by the end of this year—a 10% increase over 1950. But this expansion has begun to run into the critical shortages of steel, aluminum and copper—all used in generating equipment—and it is very questionable whether it can be expected to continue at the same rate.

Now the interesting fact is that all of this increased capacity will be spoken for by the time it comes in, and this means that any new demand on the part of the AEC must be met by new facilities, which in turn means getting into the already-short supplies of metals still further.

As far as manpower is concerned, our total demand is not, relatively speaking, very great. Currently, for example, we and our contractors are using directly only about 120,000 of the nine million or so people engaged in defense work of some kind. But here, too—as with materials—we have a disproportionately large demand for certain critically short specialties.

As an example, we might take engineers. Currently there are some 400,000 engineers in this country, and virtually all of them are working. The atomic-energy program presently employs about 6,500 engineers of various types, and an expansion program will greatly increase this demand.

It is also interesting to note that of the 12,000 physicists in this country, 1,200 of them work directly for the atomic-energy program.

Construction labor is also a factor. Of the about three million people currently comprising the construction labor force of the United States, about 52,000 are now working for the AEC, and even without another expansion program our bite will go up still further before it begins to come down. At its peak, our demand at the Savannah River plant alone will amount to more than 40,000.

These are the kinds of factors that are being taken into consideration in our current expansion studies, and they are being considered in the light of the following hard facts:

1. That any new expansion upon which we may embark will be over and above the Atomic Energy Commission's allotted place in the present defense production program—the program that is expected to level off about the end of next year with a 20% take of the total national productive effort.

2. That any new expansion will be in competition for materials and manpower, not only with civilian needs, but also with other needs, and, to some extent, with the needs of our own current construction program.

3. That the dollars and skills and materials invested in a new expansion program will not produce any additional weapons until several years from now, whereas the extra security we are buying with our current expansion will be available much sooner.

And now let us see just what it is that we will be expanding if and when we undertake a further enlargement of the atomic-energy program. Physically, we will be expanding an industrial and scientific enterprise in which the capital investment already amounts to something like two and a half billion dollars, and in which this investment will eventually climb to around five billion dollars on the basis of the expansion program already under way. By way of comparison, it is interesting to note that when this current expansion program is completed, the atomic-energy enterprise will have a larger investment in plant and equipment than the U. S. Steel and General Motors corporations combined. The operating cost of this business—as distinct from the construction costs—will amount to around six hundred million in the current fiscal year.

As a sidelight on how deeply we penetrate the economy, and on how much we must rely on many different industries in such expansions, I would like to refer briefly and specifically to the Savannah River project, which, as I mentioned earlier, is one of the main ingredients in our current expansion effort. In the 12-month period ending last September we obligated approximately $650-million on this project. We have one prime contractor—the duPont Company—which is responsible to us for this entire job. DuPont, in turn, in the same period, passed on more than 325-millions of these dollars to over 1,500 other concerns, of which 11 received subcontracts of $5-million or more, 81 received subcontracts of 500 thousand dollars or more, and 386 received subcontracts of 25 thousand dollars or more. From the standpoint of volume, 70%, and from the standpoint of value, 24% of these awards went to small business concerns, percentages which apply rather generally throughout the whole atomic-energy program.

While we are now concentrating on meeting our immediate military requirements, we can also advance the state of the art to the point where there is something in this atomic-energy business for everyone.

One way to do this is to bring in more industries—to widen and diversify our industrial and scientific base. Our expansion programs help us to accomplish this. At present there are about 600 industrial and scientific organizations involved in a major way in the atomic energy program, and these employ approximately 115,000 people as against less than 6,000 who work for AEC directly. Our current expansion effort is serving to increase this number of private concerns and institutions—and therefore the number of people in this country who are knowledgeable in the field of atomic energy and who can give the program the benefit of their imagination and enterprise.

To those firms not yet in our program, I want to urge them to give serious consideration to the idea of joining it, not only because the economic and military strength of our country depends to a large extent upon the depth with which this enterprise penetrates into the economy, but also because beyond the weapons, beyond the expansions and beyond our immediate problems there lies the peacetime promise of the atomic age.

British View of Nuclear Power

By SIR JOHN COCKCROFT*
Director, British Atomic Energy Research Establishment
Harwell, England

THE OBJECTIVE [of nuclear reactors] is to supply the world and particularly this country with an additional source of energy to supplement our existing overstrained and diminishing reserves of conventional fuel. It is worth while to point out that our requirements for electric power have increased by 50% since 1940 and are expected to increase by 45% by 1960. This alone would require an additional 13-million tons of coal by 1960.

I should also like to point out that our power consumption per operative worker is only about 30% of the equivalent U. S. power consumption and that the increased productivity, which can alone give us the increased standard of living we so desire, must inevitably depend on greater power availability in industry. There are, of course, other ways of supplementing our effective energy resources, particularly by using fuel more economically. The long-term plan of the Coal Board should also increase our coal supplies.

Nevertheless, there is every reason to develop energetically the application of nuclear energy. I cannot emphasize too strongly, however, the fact that we do not expect to produce a *cheaper* source of power than that derived from coal—it is likely, in fact, to be somewhat more expensive. What we are aiming at is to *increase* the total power available.

The only method of utilizing nuclear energy which is in sight is to use the nuclear reactor as a source of heat to replace the fuel burners of a conventional power station. The heat must then be transferred to a boiler to generate steam which in turn drives a steam turbine, or, alternatively, it may be possible in the longer term future to use the heat to drive a gas turbine.

The present normal power level of BEPO (British Experimental Pile)† is about 4 megawatts. At this power the temperature of the surface of the fuel elements is 200° C and the exit air temperature is 80° C. We are now changing our fuel elements to an improved type which we expect will allow us to increase the surface temperature and the exit air temperature. We have recently installed a heat exchanger in the exit air duct and are extracting some of the heat to use for heating Harwell buildings (see p. 70, this issue).

BEPO was not designed for utilization of heat. The amount of heat developed will only be about 200 kilowatts per ton of uranium, even when we increase the power. If we wished to design a pile of this general type for power generation, we should provide a much greater transfer of heat from the fuel elements to a steam boiler. The amount of heat developed per ton of uranium is limited mainly by the rate at which we can remove heat. We should, therefore, probably transfer the heat by a gas under pressure and would preferably use a gas with good heat-transfer properties such as helium.

We should also increase the temperature of the exit gas to enable us to

* From Joule Memorial Lecture, presented before Manchester Literary and Philosophical Society, Nov., 1951.

† This is the larger of two piles at Harwell. For a description of its design, see NUCLEONICS **8**, No. 6, 36 (1951); for details of the smaller pile, see NUCLEONICS **8**, No. 1, 3 (1951).

develop steam at a reasonable temperature and pressure which would give a reasonable thermodynamic efficiency for our power conversion. If we use aluminum cans our surface temperatures would probably be limited to 350–400° C so that the thermodynamic efficiency might not be more than 20–25%. Nevertheless this would be a possible way to start. Increased temperatures could probably be obtained by using more exotic materials for the canning of the fuel elements—elements such as zirconium or beryllium.

The natural-uranium, graphite-moderated reactor is, therefore, a possible starter as a nuclear power unit. What are its technical disadvantages? The main technical disadvantage is its large size; for a power producer would be somewhat larger than BEPO, and this is rather large to pressurize.

An alternative to a graphite-moderated pile of this kind would be one moderated by heavy water. This brings the size of the pile down considerably. An example of this is the Chalk River heavy-water pile. The reacting core is a tank of heavy water containing about 180 uranium metal rods. A pile of this kind might be developed as a power producer by pressurizing the tank and transferring the heat by circulating the heavy water, or by transferring the heat directly from the fuel elements to the boiler.

What about the economics of natural uranium power producers? The first question is the fuel cost. This obviously depends on how much heat can be extracted per pound of uranium before the fuel elements have to be changed. What is it that sets the limit to the "burning time?" The effective fuel is the U^{235} in the rods, and this is consumed as the heat development proceeds. This together with the absorption of neutrons by the fission product itself would lead to loss of K or reactivity (rate of multiplication of neutrons). However, the burning of the U^{235} is partially compensated by the breeding of a secondary fuel Pu^{239}. Of the 2.5 neutrons which are on the average emitted for each U^{235} atom destroyed, one is required for the chain reaction, some are absorbed wastefully or escape, but some are captured in U^{238} to produce Pu^{239}.

The production of this secondary fuel tends to increase the reactivity so that its general course will depend on the balance between these factors.

I will assume as an example that we extract heat at the rate of one megawatt per ton. This means that we burn up about one gram of U^{235} per ton of uranium per day. In 10,000 days or 30 years at 50% operating time, we shall, therefore, burn up 1% of the total uranium. On the most pessimistic of these assumptions we should have burnt about half of the U^{235} in the fuel elements before changing them.

Cost of Power

The over-all cost of power generated is the sum of fuel costs, capital charges and operating costs. The cost of a standard British 50 megawatt power station is about £3.5-million. A nuclear power station would be more expensive because we should have to add the reactor and should save very little of the conventional units. We do not have any accurate figure for the additional cost but, since for the sake of illustration we assumed that the capital cost is doubled, we can calculate the cost of power per unit on our three assumptions as to fuel utilization and for three alternative figures for the cost of fuel elements. The result does no more than show that the cost of nuclear power from such reactors will not be very different from the cost of power from coal—most probably it will be somewhat more expensive but not much.

The final major factor of importance in deciding on the worthwhileness of a nuclear power program based on natural uranium is the availability of uranium. At the present time, most of the uranium output of the world is devoted to military purposes, but if we can be sufficiently optimistic to believe that this is a passing phase, we can inquire what contribution can be made to our power needs by each multiple of 100 tons of uranium a year. On our three assumptions as to utilization this would mean that we could burn 1, $\frac{2}{3}$ or $\frac{1}{3}$ tons of U^{235} per year or 2,700, 1,800 or 900 grams a day. This in turn would develop, at 25% efficiency: 2,700, 1,800 or 900 megawatts of heat or 675, 450 or 225 megawatts of power or 13.5, 9.0 or 4.5% of our present power.

This, then, is the general picture of natural-uranium power reactors. They seem likely to be technically feasible. Their contribution to United Kingdom power needs would be worth while if supplies of uranium were adequate. Their poor efficiency of utilization of uranium will, however, make them unattractive as a final answer to nuclear power development.

The major objective of a nuclear power program must, therefore, be to develop reactors which will burn a much larger proportion of the total uranium. If we could burn 60% of the total uranium, the United Kingdom power requirements could be satisfied by only 10 tons of uranium a year. This objective may be realized by a thoroughgoing development of the breeding principle in which reactors breed more nuclear fuel than they consume.

Let us now see how the absorption of neutrons varies with their energy. They are emitted in fission with a maximum energy of a few million volts. In a graphite-moderated reactor they are slowed down to energies of about $\frac{1}{10}$ volt. If we look at a typical curve for the absorption of neutrons of different energies, we see that they are most strongly absorbed when they are slower. In order to reduce wasteful absorption we must, therefore, make them produce fissions or new fuel atoms before they are slowed down too much. We can do this in principle by building so-called fast or intermediate reactors in which little or no slowing down medium is used.

Fast Reactors

A fast reactor might, therefore, consist of a very compact core of almost pure U^{235} which was surrounded by a blanket of thorium in which new fuel, U^{233}, would be bred. U^{233} is a third kind of nuclear fuel. Alternatively we might have part of the thorium and some U^{238} mixed with the U^{235}.

The principal technological problems of fast reactors arise from the need to remove a large amount of heat from a very small reacting core. For this reason liquid metals which have very good heat-transfer properties and low pressures at high temperatures will be used as heat-transfer fluids. We have, therefore, to develop the technology of liquid-metal coolants. We may also experience serious metallurgical problems due to the very intense bombardment inside the core of the reactor—which will be an order of magnitude worse than in the graphite-moderated reactors since the density of neutrons will be higher in the smaller core.

An experimental fast reactor has operated for some time in the United States at Los Alamos, and the announce-

ment has just been made that a fast reactor designed for the study of breeding has been started up in Idaho.

Work is also proceeding in this country on the technology, the development problems and the design of a fast reactor.

Mobile Reactors

I have not so far referred to the development of mobile nuclear power units, but you will have read accounts of the development of nuclear power units for submarine and aircraft propulsion in the United States. In this country design and feasibility studies of mobile reactors have been in progress for some time.

The objectives of such development are clearly to make possible long voyages without refueling. A very elementary calculation shows that this is feasible in principle. Thus a reactor developing 10,000 kw of power at 25% efficiency would need to develop 40,000 kw of thermal energy and would, therefore, burn about 40 grams of fuel a day.

Fuel costs are not of first importance for such special purposes. Let us assume we were willing to pay 10 times a normal electricity fuel cost of 0.3d. per kw hour. One gram of U^{235} produces 6,000 kw-hours of energy and would, therefore, be worth 6,000 times 3d. or £75, if we could assume 100% utilization. At 20% utilization we could still afford to pay £15 per gram for U^{235}.

The technical problem is to develop reactors which with their shielding are sufficiently light for mobile power units. This requires that the reacting core should be kept to small dimensions by the use of fuel in which the concentration of U^{235} is increased above normal. It is known already that by using sufficiently highly enriched fuel a reactor can be designed to operate in a two-gallon drum. The limit to the core diameter will be set in fact largely by the need to extract about 50–100 megawatts of heat from the core. We may assume, however, that this is possible since such reactors are now being built.

Apart from this the problems are very largely the metallurgical problems of the fuel elements, the prevention of corrosion and the engineering problems of heat transfer and design. I think we may assume that mobile reactors are feasible for ship propulsion though they will be expensive power units. Aircraft propulsion units are likely to be much more difficult.

The greater part of our effort in this country has, up to the present, been devoted to the development and construction of facilities for the production of nuclear fuel, since our wartime collaboration with the United States and Canada left this country with no such facilities at the end of the war. We began effective work in mid-1946 and in a little over five years have built up the considerable technological facilities of the Harwell Research Establishment. We have also established a production organization centered at Risley in this country which under the direction of Sir Christopher Hinton has built the Springfields and Windscale factories for the production of nuclear fuel.

In my view at least, this has been a remarkable engineering achievement. These activities have, however, absorbed the greater part of our limited strength. About 10% of our effort has, however, been devoted to developing the nuclear technology which is the basis of the future power program. This effort is now being increased.

Nuclear Technology

The main divisions of nuclear technology are first, the development of the special atomic-energy materials—uranium, thorium, beryllium, zirconium and graphite. Second, the development of fuel elements of natural uranium or uranium with a high proportion of U^{233}, which will be stable metallurgically under the intense bombardment by neutrons and fission fragments in the interior of reactors. Third, the development of heat-transfer systems such as a liquid-metal system, which will withstand the severe conditions inside reactors. Fourth, the development of designs and operating techniques which will provide for 100% safety of operation in spite of the intense radioactivity developed in all components of the system. Fifth, the development of economical chemical methods of processing spent nuclear fuel and extraction of secondary fuel in breeding systems. Sixth, the development of economic methods of storing of radioactive wastes.

You will see, therefore, that the chemists, chemical engineers, engineers and metallurgists have a larger part to play in the development of nuclear power technology than the physicists although they, too, have their role in determining the nuclear properties of reactors.

I cannot speak in any detail about the development of nuclear technology since most of it is still secret. During the five years of work in this country we have established the production of uranium, thorium and graphite in the very high purity quality required. We are also developing the production and technology of beryllium metal and zirconium. An active metallurgical research and development division has been built up at Harwell which has contributed greatly to our reactor program and has at the same time made considerable contributions to the basic metallurgy underlying our project. Our chemists and chemical engineers carried out a great deal of the early work on the basis of which the large-scale chemical extraction plants were designed. They are now beginning to work on the further development of the technology of separation of the fissile materials from uranium or thorium and the fission products which would be required in a breeder program.

The disposal of radioactive waste at one time seemed to be one of the major problems of a large-scale atomic-energy program. Nuclear power stations developing 1,000 megawatts of electric energy would produce in one year radioactive fission products having a total activity of 100 million curies. . . Methods are now being developed which should make feasible putting these wastes to use for practical purposes.

You will see, therefore, that nuclear power is in an early development stage, during which the first experimental power producers are being designed, built and tested. There is a growing confidence amongst the workers in the field that the technological problems will be solved. Our preliminary studies of costs show also that nuclear power costs are likely to be of the same order as the cost of power from coal. There is no point at all at the present time in splitting hairs and asking whether it will be a fraction of a penny less or more expensive than coal since only experience of operation can enable estimates of this accuracy to be made. We have been engaged for a year on design and feasibility studies of the more important type of reactor. The essential thing is now to get on and build some power reactors. —END

Radioisotope Production in the United States

Involved in the more than 20,000 shipments of radioisotopes by the AEC are problems of reactor operation, chemical processing, and handling of active materials. Here is a summary of what the problems are and how they are solved

By PAUL C. AEBERSOLD*
Chief, Isotopes Division
U. S. Atomic Energy Commission
Oak Ridge, Tennessee

and A. F. RUPP†
Oak Ridge National Laboratory
Oak Ridge, Tennessee

To SUPPLY radioisotopes for research, industry, and therapy in the United States, the AEC has developed what amounts to an industry in itself. It has grown from making 246 shipments in 1946, passing the 1,000 shipments per year mark in 1948. By the end of last September, 20,943 shipments had been made since the program was started. The yearly number of shipments and amount of activity handled is still increasing.

To make this schedule of shipments possible, large investments have been made in reactor facilities, in processing equipment, and in equipment for handling radioactive materials. A considerable part of this capital expenditure was necessary because of the nature of the product. In fact, the magnitude of the radioisotope production process is directly related to the myriad problems encountered during production. Thus a discussion of these problems and their solution will give a good picture of radioisotope production today.

There are two main divisions in the production process—irradiation of material in a reactor to produce radioisotopes, and the processing of the irradiated material to purify the desired product. Each of these is discussed here, but more emphasis will be placed on the second step, processing, since the reactor operation parallels that described by F. W. Gilbert on page 6 for the Canadian NRX reactor.

Reactor Problems

In general, the suitability of a reactor for radioisotope production depends on a combination of three characteristics: excess reactivity, neutron flux, and available irradiation space. The most important of the three, however, is excess reactivity, that is, the number of neutrons in excess of those required to sustain a chain reaction. But, to produce radioisotopes of high specific activity, it is necessary not only to have a sufficient number of neutrons available for bombarding the target material; a high density of neutrons—high neutron flux—is also required.

It is obvious that sufficient space must be available in the reactor for irradiating the target material. As Gilbert points out in his article on page 6, a large volume at medium flux is sometimes preferable to a small volume at high flux.

Other reactor design and operating characteristics that influence suitability of a reactor for radioisotope production are operating temperature, sample-hole size, and facilities for charging and discharging samples.

Actually, none of the AEC reactors were designed specifically for the purpose of producing radioisotopes. The Oak Ridge reactor, where most of the radioisotopes are produced, was built as a pilot plant to study the production of plutonium, and it lacks some of the characteristics that would be useful for radioisotope production. This is a limitation that creates many problems.

For example, the production of P^{32} places a heavier demand than any other radioisotope on the volume of space allocated to production in the Oak Ridge reactor. At present more than 10% of the available space is devoted to the irradiation of sulfur from which the P^{32} is obtained. It will not be possible to expand the production of this short-lived material further without reassignment of reactor space now being used for other problems or without modifying the design of the reactor.

The preparation of I^{131} might have caused a similar problem if production methods had not been altered. Originally, I^{131} was routinely prepared by an

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* The information on reactor operation is taken from a paper presented at the 12th International Congress of Pure and Applied Chemistry, New York, Sept. 10, 1951.

† The information on processing equipment is taken from a lecture given at a conference on "Radioisotopes in Industry" at the Case Institute of Technology, Cleveland, Ohio, April 3, 1951.

(n,γ) reaction on Te^{130} to form Te^{131} which decayed to the desired product. Today, radioiodine is exclusively obtained as a fission product; its production thus does not take irradiation space in the reactor.

Processing Problems

Irradiation in a reactor is usually only the beginning of the radioisotope production process. To obtain the desired product in the form required, chemical processing is necessary. Among the processes used are distillation and gasification, ion exchange, solvent extraction, electrodeposition, precipitation and co-precipitation, crystallization, and adsorption of radiocolloids.

One ordinarily thinks of the chemical industry in terms of huge apparatus. Tons of chemicals, plastics, and fuels are produced. The product of radiochemical operations, in terms of weight, is in most cases very minute, although the amount of radioactivity may be very large. Thus, the equipment may be very small, especially in the final processing stages. However, the intense radiation which is encountered makes it necessary to surround the processing equipment with tons of heavy shielding material and to conduct operations by means of intricate and expensive remote controls.

Handling of Fluids

Undoubtedly, the simplest way to handle radioactive materials is in fluid form. The handling problem then becomes one of providing suitable tanks or containers, specialized liquid processing equipment, pipe lines, valves, fittings, and a method of forcing fluids from one place to another.

In the usual chemical plant, liquids are pumped from one point to another. This method has been avoided in radiochemical processing because of possible leakage at packing glands and mechanical failure of the pump or motor, which would involve a very difficult maintenance problem. As newer types of packless pumps of very high reliability are developed, the pump will resume its traditional role even in handling radiochemicals.

Two methods are generally used for transferring radioactive fluids, depending upon the size of the equipment: (a) pressure-vacuum on a closed system of tanks (as blow-pots and acid eggs are used in common practice) for small equipment; (b) steam, air, or water jets for large equipment. It will be noted that in neither of these cases is there any moving or power-driven part in contact with the liquid. Generally speaking, these two methods have worked quite well except that vacuum transfers require heavy-walled tanks and complicated piping, and jets are extremely inefficient, often hard to start, and blow out mists at the end of a transfer before the steam or air is turned off.

Piping problems are normal except that the restrictions imposed by shielding are a trial to even the mildest-mannered pipefitter. Since stainless steel or other equally hard-to-handle alloys are usually used for piping and equipment, the problem of avoiding leaks is considerable. All fittings and valves are avoided unless they are absolutely necessary. Field welds on small-sized stainless lines have been found to be very unreliable, with pinholes showing up after months of service.

Diaphragm and bellows valves are used to some extent where space is available for their installation. When piping is imbedded in concrete, as high as 50% extra spare lines are left for contingencies.

Unusually good results have been obtained with union connections, and valves and stainless-steel tubing with union connections will probably be used more as time goes by. The use of tubing rather than pipe offers many advantages in setting up equipment in shielded areas where space is limited; in the smaller sizes, many fittings may be avoided by streamline bending. Streamlined piping is very important where jets are used.

All valves that can be are placed outside the shielding. Other valves, which must be operated by remote-control handles passed out through the shielding, must be placed with great care, keeping the axiom in mind that although 100 nonradioactive test runs have been made with no leaks, as soon as the cell is closed and a radioactive run is started, a leak will surely develop. This, of course, has nothing to do with radioactivity but is merely the perversity of Nature, or so it seems to those charged with getting a hot cell into operation. This means that valves, lines, fittings, and equipment must be placed so that maintenance work can be done quickly and easily.

Gravity flow is desirable in any

NUMBER OF SHIPMENTS

A total of 20,943 domestic shipments of radioisotopes was recorded by the Isotopes Division of the U. S. AEC from August 2, 1946 to September 30, 1951. This can be broken down as . . .

(Classified by use)

9,920 . . . Medical therapy
4,599 . . . Animal physiology
1,386 . . . Physics
1,063 . . . Chemistry
928 . . . Plant physiology
880 . . . Industrial research
354 . . . Bacteriology
1,482 . . . Other
331 . . . General research and development

(Classified by isotope)

7,779 . . . Iodine-131
6,228 . . . Phosphorus-32
993 . . . Carbon-14
828 . . . Sodium-24
443 . . . Sulfur-35
483 . . . Gold-198
326 . . . Calcium-45
246 . . . Iron-55, 59
405 . . . Cobalt-60
358 . . . Potassium-42
139 . . . Strontium-89, 90
2,715 . . . Other isotopes

ACTIVITY OF SHIPMENTS

Another indication of the size of the radioisotope production program is given by these figures for activity processed and shipped from Oak Ridge National Laboratory.[1]

In August, 1951, ORNL shipped . . .
35,436 mc of iodine-131
9,092 mc of phosphorus-32
334 mc of carbon-14
20,412 mc of cobalt-60

In September, 1951, ORNL shipped . . .
35,936 mc of iodine-131
9,120 mc of phosphorus-32
304 mc of carbon-14
98,898 mc of cobalt-60

plant, and nonradioactive chemical solutions and water are almost always added this way, from outside the shielding. However, this very practical method is seldom used with radioactive solutions because it becomes necessary to valve off at the bottom of the tank against the hydrostatic head above it. In case of leakage or valve failure, the contents of the tank will be lost, with possibly disastrous consequences. Therefore, most tanks have solid bottoms and liquids are drawn out through dip legs.

Fortunately, it is seldom necessary to measure the rate of flow of radioactive solutions. For very small flows, a drop-counter is used and the drops counted by watching through a periscope. This is not too satisfactory, for after a while the radiations blacken the glassware and one cannot see the drops. A dodge used in this case is to have the drops fall between two platinum electrodes so that a light or electrical counter outside the cell is activated.

For somewhat larger flows, a variation on the weir box is used, except that it is completely closed and the atmospheric vent is carefully controlled so that overflows go to the hot drain. In this case, the height of liquid building up above the orifice is measured visually or with platinum electrical contacts sealed through the glass.

Rotameters are excellent for measuring liquid flow outside the cell, but there are few cases where they have been used for radioactive solutions. Many ingenious ways have been devised for remotely measuring fluid flow, but these are almost always variations on the familiar weir or orifice pressure-drop methods.

Pressure and Liquid Level

Measurement of pressure, in so far as the external instruments are concerned, is about the same as in usual practice. Vertical and inclined manometers, Bourdon gages, and bellows draft gages with various recording apparatus are generally used. The danger involved in using any pressure-measuring device is that radioactive fluid or gas may be forced outside the shielding into the instruments on the panel board. Therefore, diaphragms are used in the line leading from the cell, or secondary pressure pots of large enough size to take care of blowbacks are placed inside the cell. The use of strain gages on very ruggedly constructed Bourdon tubes inside the cell is being studied.

Liquid level is conveniently determined remotely by use of the dip tube in which air pressure is balanced against the hydrostatic head in the tank. Air is bubbled through the tube into the tank at a controlled rate and the pressure measured at the panel board. A reference tube at the top of the tank is generally used so that a correct differential pressure is obtained whether the tank pressure is above or below atmospheric pressure.

This method, of course, gives a value proportional to the weight of liquid above the exit of the tube. However, the specific gravity may be determined by the same method by introducing another air leg at a known distance above the long leg, also immersed in the liquid. The differential pressure between these two legs enables one to calculate the specific gravity of liquid and, further, the volume of the liquid from a weight measurement.

This method has many disadvantages, including all those cited for pressure gages. Furthermore, the dip tubes sometimes become plugged with sludge or crystals, and there are some processes where it is undesirable to bubble gas into the solution.

For very large underground tanks, one of the oldest and simplest devices is used, a float gage attached to a wire and pulleys which activates a tell-tale on a vertical calibrated board. In some tanks where one merely desires to know whether the tank is full, half-full, or empty, platinum electric contacts may be used to good advantage. Some devices have been made to use the radioactivity of the fluid itself as a height measurement by monitoring with a movable ionization tube. Other devices involving the changes in capacitance in a fixed electrical circuit are also feasible. Glass vessels are used to a great extent, and the liquid level in these is readily determined visually.

Heating and Cooling

The method chosen for heating or cooling depends upon the temperature range desired, the type of material used for processing equipment, and the scale of the operation.

Where relatively large metal equipment is used and the temperature ranges from about room temperature to 200° C, steam heating and water cooling in coils and jackets are generally used. Very little unconventional design is encountered, beyond insuring that control valves and steam traps are located outside the shielding. All heating and cooling equipment is put through long and severe testing before hot operations are started.

At higher temperatures and where high jacket or coil pressures are not permissible, Dowtherm or similar heating may be used. Brine or Freon may be used for gaining low temperatures.

To a very great extent, radiochemical operations are conducted in both large and small glass equipment to avoid metallic contamination and allow process changes to be observed. Heating of glassware is accomplished by many of the familiar laboratory methods. Gas heating with a well-distributed gas flame and specially-designed mesh flask-protector is used. The flame is ignited remotely by an electric spark. This method has the advantage that the burner may be moved out of the way, by remote-control mechanisms, and the flask cooled by water sprays.

Electric heating mantles are very useful, especially for the large flask sizes. Cooling is more difficult in this case, but the mantle may be lowered a few inches and a blast of cold air passed around the flask for cooling. Electrical immersion heaters have been used with limited success.

One of the most useful methods is heating with batteries of infra-red heat lamps. This method allows even heating with no contact, low heat capacity for quick cooling, and good observation of the flask. Disadvantages are low efficiency, bulky equipment, and high burn-out rate.

Temperatures are easily measured by remote control with resistance thermometers or thermocouples.

Relatively few cases arise for high temperatures such as are used in metallurgical or ceramic work. Where very small amounts of radioactive materials are to be heated to high temperatures, this is usually done *in vacuo* on platinum or tungsten filaments. In other cases, conventional electric resistance or induction furnaces have been used with special provisions to contain the radioactive material and toxic fumes.

Evaporation and Distillation

Evaporation and distillation processes, with a few exceptions in which C^{14} organics are fractionally distilled,

are handled in the elementary pot still and condenser, operating under a slight vacuum. The part of exceptional importance is the condenser vent which is connected to a vacuum exhaust line containing equipment to remove mist and discharge noncondensables into a decontamination system and then to a high stack.

It is good practice to have all equipment closed and vented to the vacuum exhaust line so that the equipment is at a lower pressure level than the cell in which it is placed. The cell itself is also well ventilated and maintained at slightly below atmospheric pressure. This double line of defense is necessary to prevent contamination of the air breathed by operating personnel.

Solids Separation

The solid-bowl centrifuge has been successfully used for removing radioactive precipitates in all sizes of operations. The centrifuge can be operated by remote control, the effluents handled easily, and the residual cake dissolved in the centrifuge bowl. The main objections to the centrifuge are that it is a power-driven device subject to mechanical failure and that it tends to create sprays or mists which are distributed into the air unless it is carefully covered and vented.

In cases where time is not a factor, settling in a cone-shaped vessel is often satisfactory. Precipitates carrying radioactive materials are usually very small in volume and are separated from relatively large volumes of liquid, so that it is necessary to collect the precipitates at the apex of a cone for easy removal.

Sintered-glass, plastic, and stainless-steel filters are used for filtration. Filtration through paper or standard type filters is usually not practical when working with radioactive materials. Filtrations are done in Stang reactors and controlled entirely by pressure and vacuum, or inverted filter disks on filter sticks are used. The latter practice is convenient in that the cake may be backwashed off the filter into the vessel very easily, if the filter becomes clogged.

Instrumentation

Normal instrumentation, such as recording equipment for temperature and pressure, are used plus a great variety of instruments for measuring radioactivity. The instruments may be portable ionization chambers, Geiger-Müller count-rate meters, electrometers of various types, automatic counting absorption curve machines, high-pressure gamma chambers, and many other similar instruments. Since radioactivity can be detected only with instruments, such equipment is the very heart of every process. New instruments are constantly being developed which will eventually allow almost complete automatic control of processing.

Lead Shot for Gamma-Ray Shielding

LEAD BRICKS are commonly used to shield a source of gamma radiation. But if the source is to be used in complicated equipment, lead bricks cannot always be placed to give maximum protection without interfering with operation of the equipment.

A. Nightingale of the Physics Department, Guy's Hospital Medical School, London, has reported* that cavity walls made of sheet iron and filled with 0.1-in. lead shot may be used to replace solid lead walls used to protect personnel against gamma radiation. The lead-shot walls are not suitable for shielding photographic materials.

Theoretical considerations showed that the lead shot could assume two configurations within the wall, hexagonal and cubic. In the hexagonal arrangement, the first layer and the third are alike; in the cubic, the first and the fourth. There are four directions in the hexagonal and six in the cubic in which holes can pierce the entire structure. The theoretical variations in effective path length through the wall and emergent intensity were calculated. For a 3-in. wall, the mean lead equivalent was 2.2 in., and ratios of 18.5 and 0.36 were obtained between the mean emergent intensity and the maximum and minimum emergent intensities, respectively.

Radiographic tests of two specimens gave uniformly mottled films. Using a densitometer, it was found, however, that the density varied only 15% above and below the mean. Thus the experimental variations in emergent intensity are much smaller than those predicted by calculation.

Further tests indicated that the lead shot was not closely and regularly packed, and that the emergent radiation was mainly primary gamma radiation and not secondary scattered radiation. It was found that the diameter of the shot used should not be greater than the effective diameter of the source to be shielded.

A collimated end-window G-M counter was used to compare solid and lead-shot shields; the results are shown in the table. The results were reproducible within the 2% counting error, and, therefore, it is felt that it is not necessary to shake down the lead shot after it is poured in.

On the basis of the data, lead-shot shielding less than 1.4 in. thick should not be used.

Appreciable local variations in the intensity of the radiation transmitted by the lead-shot walls occur. However, this transmitted radiation would be serious only if a person remained stationary within 0.1 in. for a long period of time.

Comparison of Shielding

Thickness of solid lead (in.)	*Equivalent thickness of lead shot 0.1-in. diameter (in.)*
0.5	0.75
1.0	1.40
1.5	2.10
2.0	2.77
2.5	3.50

* *Brit. J. Radiology* **24**, 568 (1951)

TABLE 1 — Comparison of Some Heat Transfer Fluids for High Temperatures*

	Sodium	*NaK (44% K)*	*HTS†*	*Dowtherm A‡*	*Mercury*	*Lead*	*Pb-Bi Eutectic*	*Lithium*	*Water*
Melting point, °F	208	65	290	55	−37	622	257	367	32
Boiling point (14.7 psi), °F	1,616	1,518	.....	485	675	3,170	3,038	2,403	212
Liquid density, gal/cm³ approx.	0.9	0.9	1.7	.....	13	10	10	0.5	1
Specific heat, Btu/lb °F	0.33–0.30	0.28	0.373	0.63–0.69	0.033	0.034	0.035	1.05–1.22	1.005
Thermal conductivity, $\frac{(\text{Btu})(\text{ft})}{(\text{hr})(^\circ\text{F})(\text{ft}^2)}$	49–38	14–16	.....	0.105	5–9	8	5.3–6.5	24	0.406
Heat-transfer coefficient, $\frac{(\text{Btu})}{(\text{hr})(^\circ\text{F})(\text{ft}^2)}$ §	6,400	3,500	1,500	200–300	5,700	4,100	3,700	5,800	3,000
Pumping power (Water = 1)§	0.925	0.925	1.92	0.925	13.1	11.5	11.5	0.5	1
Heat capacity (Water = 1)	0.24	0.185	0.63	.....	0.42	0.38	0.30	0.48	1

* Based on information from ref. (1).
† Heat-transfer salt composed of $NaNO_2$, $NaNO_3$, and KNO_3.
‡ Eutectic mixture of diphenyl and diphenyl oxide.
§ 10 ft/sec in 1 in.-dia. tube.

Engineering Aspects of Liquid Metals for Heat Transfer

Work accomplished with developmental systems indicates that liquid metals hold considerable promise as reactor coolants and heat-transfer fluids for systems operating above 600° F

By THOMAS TROCKI
Knolls Atomic Power Laboratory
General Electric Company
Schenectady, New York

LIQUID METALS for use as heat-transfer fluids for high-temperature service (above 600° F) have aroused a good deal of interest in recent years. In particular, they appear suitable as coolants for high-temperature nuclear reactors, as would be required for power production.

Although special precautions are required for the safe use of liquid metals, their handling seems feasible on the basis of work accomplished to date. This work has included the construction and operation of developmental heat-transfer systems of varying size and complexity. These systems used lithium, sodium, sodium-potassium alloy, and lead-bismuth alloy.

The relatively high thermal conductivity of metals compared to the usual heat-transfer fluids (i.e., water, Dowtherm, heat-transfer salts and oils) is probably the outstanding property contributing to their superiority as heat-transfer fluids.

Other important properties of metals for high-temperature service are relatively high boiling point or low vapor pressure, and chemical and thermal stability. The metals considered for this use are limited only to those with a reasonably low melting point to minimize the difficulty of keeping the metals liquid during handling. Lithium, sodium, potassium, lead, lead bismuth, and mercury are currently the more promising metals.

The properties of liquid metals make them particularly attractive as coolants for high-temperature reactors. They are comparatively stable in radiation and also have a sufficiently high boiling point to minimize the possibility of boiling in the reactor. Their low vapor pressures at high temperatures permit their use in low-pressure systems. This means that the pressure stress can be a small portion of the total stress in piping and equipment.

The heat-transfer capabilities of liquid metals are best illustrated by comparing the performance of various fluids under comparable conditions, say, heat transferred to the fluid flowing at 10 ft/sec in tubing 1 in. in diameter.

The heat transferred to the fluid from the wall is expressed by the equation $Q = h\ S\ \Delta t$, where Q is the quantity of heat transferred, h is the heat-transfer coefficient, S is the wall area for heat transfer, and Δt is the temperature difference between wall and fluid.

In this relationship, only the heat-transfer coefficient is dependent upon the fluid properties. Taking into account the conditions assumed above, this coefficient is evaluated for various fluids in Table 1. Under these conditions, the heat-transfer coefficient of lithium is seen to be about twice as high as water. From the relationship given above, it is apparent that with a higher heat-transfer coefficient the same heat can be transferred either through a reduced area or with a lower temperature difference. Both effects are usually desirable in heat-exchange equipment.

The heat absorbed by a fluid flowing in a tube is determined by the relation $Q = W\ c\ \Delta t = (dc) \times A\ v\ \Delta t$, where Q is the quantity of heat absorbed, W is the weight flow of fluid, d is the density of fluid, A is the flow area, v is the velocity, c is the specific heat of the fluid, and Δt is the temperature rise of fluid.

In this relationship, only the quantity dc, the heat capacity of the fluid, is dependent upon fluid properties. It is a measure of the ability of a fluid to store heat. Comparison of these properties for various fluids in Table 1 shows that liquid metals fall short of water in their capacity to store heat. Lithium is outstanding in this respect because its specific heat is equivalent to water, but its density is only half.

The power required to pump the various fluids through the assumed tube at the same velocity is the other quantity of interest. The pumping power is also evaluated in Table 1. The density of the fluid is most significant in this respect.

Several generalizations can be drawn from this brief comparison of heat-transfer fluids:

1. The high heat-transfer coefficients of liquid metals compared to water permit considerable reduction in heat-transfer area or reduction in wall temperature for the same heat transferred.

2. The heat capacity of liquid metals is lower than water. To transfer the same heat, liquid metals require either a higher flow rate or a larger increase in fluid temperature through the tube.

3. The comparative pumping power for liquid metals varies from less than water for the lighter metals to much more than water for heavier ones.

A significant disadvantage of water, not directly related to heat transfer, is the fact that high pressures are required to keep it liquid at high temperature. This limitation of water led to the development of heat-transfer salt, a mixture of nitrite and nitrate salts now widely used as a high-temperature, heat-transfer fluid.

1. Handling and Safety Problems

Except for the mercury-vapor process that has been used for power generation and industrial heating and cooling operations, liquid metals are used commercially for heat transfer to only a limited extent because the economics of the usual heat-transfer systems do not warrant the high development costs required to gain the possible advantages that they offer.

The information available on most liquid metals is limited, but it is known that their handling, in many cases, is hazardous or comparatively difficult.

The alkali metals, lithium, sodium, and potassium, are extremely active chemically. They burn readily in air and react with various degrees of violence with water. Lead and lead-bismuth are corrosive to many high-temperature structural materials and, beyond a certain concentration in air, are toxic to breathe.

These hazards are admittedly somewhat unique, but are not much different from the hazards of fire, explosion, or toxicity which are present in many commercial chemical processes and which have become accepted as part of the job. Thus by cautious handling and careful design and construction of equipment, the hazards associated with liquid metals can likewise be reduced to an acceptable minimum. This has been done to a limited extent, and further improvement can be expected as their use and knowledge concerning the special properties of liquid metals becomes more widespread.

An alloy of sodium and potassium has been produced commercially in large quantities. The production process requires handling of the liquid and vapor (above 1,500° F at atmospheric pressure) and disposal of quantities of the alloy. These operations are hazardous because of the danger of fire and burns to personnel. The safety record in this work is not only good but is also comparable to that in other chemical process work of a hazardous nature.

Experience thus accumulated has been applied to and refined in the handling of liquid metal in heat-transfer systems. As the metals are used at temperatures considerably below their boiling point, the difficulty in handling is somewhat reduced. In a closed heat-transfer system at elevated temperatures, the metals are blanketed with inert gas and present no particular hazard. Alkali metals that might leak into air will burn, but fires can be controlled with powder dispensed by hand or from commercially available gas-pressure-operated dispensers. As with any fire, quick action while the fire is small makes the extinguishing job easier. Fighting large alkali fires is complicated by the dense smoke that makes visibility difficult or impossible.

Some of the metals, like lead, lead-bismuth, or mercury, are known to be harmful if breathed in sufficient concentration in air. That this hazard can be overcome is demonstrated by the successful operation of several mercury-vapor power plants in this country over a period of many years. The provisions required for safe handling of these metals are not economically prohibitive. By taking special precautions in design and construction to prevent leaks, and providing detectors and alarms to warn of leaks, these metals can be handled safely in large quantities at elevated temperatures.

2. System Design and Construction

As the foregoing discussion emphasized, leakage prevention is one of the main requirements in the design of piping systems and equipment to contain liquid metal. This applies to leakage into as well as out of the system. For instance, oxygen, which usually increases the rate of corrosion by the liquid metal, cannot be permitted to leak into the system.

To prevent leakage of liquid metal from equipment, the liquid-metal cir-

cuits must be completely welded. Flanges and other types of pressure-tight joints have been used with only moderate success in containing liquid metal in experimental systems and are not considered satisfactory for high-temperature process application.

Fortunately, design, fabrication, inspection, and testing techniques are sufficiently advanced in the field of high-temperature piping and equipment to assure sound and leak-tight equipment if one of the currently available high-temperature structural materials is used. Only the highest quality of workmanship is recommended for high-temperature, liquid-metal systems.

Liquid metals will leak through extremely small cracks or holes. Thus techniques used for leak-testing of completed piping and equipment must be highly sensitive. Although equipment can be repaired after small leakage of liquid metal, it is usually easier and less expensive to locate leaks *before* the equipment is installed and insulated. Leak-testing techniques developed for making vacuum-tight equipment give good results in liquid-metal equipment (*2*). This does not assure that the equipment will not leak at high temperature after the liquid metal has had a chance to attack weld scale and inclusions, but it does eliminate leaks that a normal hydrostatic test would not show up. The maximum pressure for hydrostatic testing is limited to a relatively low value by the low system design pressure even for high temperature.

Selection of Materials

As in any heat-transfer system, selection of materials is dictated by the temperature and corrosion of the heat-transfer fluid. Enough information is available on the more suitable (from a heat-transfer standpoint) liquid metals to permit construction and operation of experimental heat-transfer systems (*1*). Systems to test lithium, sodium, sodium-potassium alloy, and lead-bismuth have been built and operated. In most of these systems, austenitic steels and nickel were employed, the nickel being used in heat-exchanger tubes where high conductivity is desirable.

Inert Gas Blanket

Liquid metals require an inert gas for blanketing their free surfaces. This requirement does not usually present any design problem in a heat-transfer system if the system is completely sealed. Helium, argon, or nitrogen of maximum purity is used. Commercially available lamp-grade gas or equivalent is satisfactory for this purpose.

If it is required to regulate the inert gas pressure to some nominal value above atmospheric pressure, the gas system becomes more complicated. To hold a constant pressure during changing-temperature conditions, addition or venting of gas is necessary. Depending upon the amount and purity of the gas used, it may be necessary to purify the gas further at the site just before it enters the equipment.

The vent piping for gas from a liquid-metal system is susceptible to plugging in low-temperature sections of the piping by condensed vapors and entrained particles of the liquid metal, particularly in the case of a high-melting-point metal. The vapors and solid particles must be removed from the gas before entering the vent lines and the restricted passages in the vent control valves. A filter or condenser can be used for this purpose.

Keeping Metals Liquid

Since most "liquid" metals are solid at room temperature, provision must be made to heat all parts of the equipment and piping system to permit filling of the system and subsequent melting of the metal if it has solidified in the system. This is most easily accomplished by wrapping all pipes and equipment with resistance heating wire or sheathed-type electric heaters. Wire of suitable heating capacity armored with a woven wire sheath is now available. In simple systems of approximately uniform flow sections, the system can be heated by electrical short-circuit heating of the piping and equipment walls.

Insulation

The alkali metals react with some of the common pipe insulating materials. The insulation on pipes carrying liquid metals should not react with the liquid metal; by proper selection of material, the insulation can reduce the burning of liquid-metal leakage by starving the fire of oxygen. Small leaks have occurred in hot liquid-metal lines without any burning of the liquid metal. It has soaked into the insulation and oxidized slowly.

Cleanliness of System

Cleanliness in fabrication of components and construction of a system, of course, affects the performance of any heat-transfer system, but it is particularly important in a liquid-metal system. Any water, dirt, or grease left in the piping will contaminate the liquid metal, and contamination usually results in increased corrosion. Even though the completed system can be dried and outgassed by evacuation, the effectiveness of these operations is limited after a system has been assembled. Most materials left after the final cleaning will eventually contaminate the liquid metal. The purified charge of liquid metal will always pick up some contamination from the system, but how frequently repurification of the liquid metal is necessary is determined by the degree of cleanliness of the system.

3. Liquid-Metal Heat Exchangers

The mechanical construction usually followed in heat exchangers for the more common heat-transfer fluids is to roll the tubes into tube sheets and to bolt the tube bundle into the shell with gaskets between the faces of appropriate flanges. Much specialized experience lies behind the accepted configurations. So far, this kind of construction has not been considered satisfactory for high-temperature, liquid-metal heat exchangers. In most of the liquid-metal heat exchangers constructed to date, it has been necessary to weld the liquid-metal circuit completely to prevent leakage of the liquid metal. This, of course, tends to make repairs considerably more difficult and expensive.

The high heat-transfer coefficients that can be attained with liquid metal also affect heat-exchanger design. The heat-transfer coefficients of most one-phase fluids are sufficiently low so that the heat-transfer resistance of the tube-wall material is not significant in determining the over-all heat-transfer resistance. This is particularly true of

gases and is nominally true of most oils. Liquid-metal and boiling-water coefficients, however, are sufficiently high to make the tube wall resistance significant.

Table 2 shows a theoretical comparison of heat transfer through the same tube with comparable flow conditions assumed both inside and outside the tube. A 1-in.-diameter carbon steel tube of 0.1-in. wall thickness is assumed. The basic equation for determining the over-all heat transfer coefficient is used for the evaluation

$$\frac{1}{U_o A_o} = \frac{1}{h_i A_i} + \frac{X_w}{k_w A_w} + \frac{1}{h_o A_o}$$

where h and U are heat-transfer coefficients, A is area, k is conductivity, X is wall thickness, i denotes inner, o denotes outer, and w denotes wall.

Over-all resistance R_T

$$= R_{\text{inner film}} + R_{\text{wall}} + R_{\text{outer film}}$$

It can be seen from Table 2 that in a liquid-metal-to-steam generator, the tube-wall resistance is a significant part of the total resistance. In a liquid-metal-to-liquid-metal heat exchanger, this is also true, the distribution of resistance being generally similar. For minimum heat-transfer area, it is necessary to use minimum wall thickness of a high conductivity material in heat exchangers of these types.

Since much of the temperature drop occurs through the tube wall itself, the steady-state thermal stress in the tube wall is larger than usually encountered in heat exchangers. In designing a heat exchanger for minimum size, for the same heat transferred, the size can be reduced by increasing the heat-transfer coefficient or the temperature difference between the fluids. If the latter approach is chosen to reduce size, increasing the Δt in a liquid-metal heat exchanger can result in high thermal stresses in the tube wall. The effects of high, continuous thermal stress, or the cycling of the stress with time, are difficult to predict on the basis of existing experience. An arbitrary limit must be set on the stress or temperature difference.

The design of steam generators heated by liquid metal is affected significantly by liquid metals that react chemically with water. The alkali metals, lithium, sodium, and potassium, are good examples. It is necessary to take extra precautions to prevent mixing of the metal and water. Although the reaction between the two can be violent, it is not likely to be explosive, and can be vented into the steam volume and subsequently the atmosphere. The consequences of the reaction are likely to be destructive enough, however, to warrant taking extra precautions in the design and construction of the heat exchanger to reduce chances of mixing to a minimum.

TABLE 2 — Distribution of Heat-Transfer Resistances in Heat Exchangers

Inner fluid: / Outer fluid:	*Sodium* / *Boiling water*	*Heat-transfer salt* / *Boiling water*	*Gas* / *Boiling water*
R_{inner} °C	22.4	59.0	99
R_{wall} °C	33.0	17.4	0.6
R_{outer} °C	44.6	23.6	0.4
R_T °C	100	100	100
R_{Total}	11.2×10^{-4}	21.2×10^{-4}	386×10^{-4}
U (Btu)/(hr)(°F)(ft²)	890	470	18

In existing heat exchangers, the precaution taken is to separate the liquid metal and water with two independent separating walls. Concentric tubes are used, and the annulus between the tubes is instrumented to detect leakage of either fluid into it. A liquid metal not reactive with water is used in the annulus between the tubes to provide a heat-transfer bond, at the same time allowing differential expansion between the tubes. Another scheme is to bond the tubes together with copper that has been spirally grooved to provide a leak-detecting passage.

One design of steam generator takes advantage of the fact that alkali metals are not as reactive with steam (which is gaseous) as with water. In the evaporator section of the steam generator, the water is baffled to cover only the walls of the tube, leaving most of the tube filled with steam. Thus only small quantities of liquids can mix, and there is considerable expansion volume for the products of reaction.

4. Advantages of Liquid Metals in Pumping and Instrumentation

The metallic properties of liquid metals offer the possibility of using electromagnetic effects to pump the metals or to measure their movement or position in pipes and vessels. Of course, the effectiveness of this method of handling liquid metals is dependent upon the electrical resistivity of the metal and the comparative electrical resistivity of the structural material in which it is contained.

Use for Pumping

The advantage of the electrical properties of the liquid metal is best applied in the pumping process. Sealing a mechanical pump for liquid metal is quite difficult, and designs of mechanical pumps tend to be complicated. Electromagnetic pumping does away with the need for mechanical rotating equipment in contact with the liquid metal, thus eliminating the associated bearing and seal problem.

Electromagnetic pumps are basically similar to electric motors. The fundamental principle involved is the force produced on a conductor in a magnetic field described by the following equation

$$F = BIL$$

where F is the force, B is the magnetic field strength, I is the current in the conductor, and L is the length of conductor in the field.

Just as there are many variations of d-c and a-c motors, so there are possible many designs of electromagnetic pumps. The a-c type can be either the conduction type in which large currents are externally supplied to the fluid, or the induction type, similar to

an induction motor in which currents are induced in the fluid by a moving or varying magnetic field.

When a conductor is moved through a magnetic field, a voltage is induced in it. This principle can be used as the basis for measuring flow of liquid metals. A permanent magnet is mounted on the pipe in which flow is to be measured and a generated emf, which is proportional to velocity, is measured at appropriate taps on the pipe wall. This method of flow measurement is accurate over a wide flow range. The equipment required is simple and can be installed on the outside of the pipe.

Indication of Liquid Level

Liquid-level indicators based upon measurements of resistance and impedance have been built. In the impedance type, the liquid-metal level changes the impedance of a coil inserted in a tube in the liquid metal. Measurement of the change in impedance gives a measure of the liquid level. In the resistance type, the liquid metal in contact with a resistance element short-circuits the submerged part of the element. The liquid level is proportional to the measured resistance.

5. Purification of Liquid Metals

The corrosion rate of most fluids on metals generally increases with increasing temperature, and usually at a greater than linear rate. This is true of corrosion in steam boilers that require careful treatment of the water in high-temperature plants to prevent premature failure from corrosion. This problem is similar in handling liquid metals.

As in boiler water, oxygen is the principal contaminant and must be kept to a practical minimum. In many cases, filtration of the liquid metal, at ordinary handling temperature, through a filter of extremely fine pore size (in the order of microns) has produced liquid metals of acceptable purity. Metal thus purified, sealed in a clean system, has required no further attention.

As most experimental systems need to be opened for repairs or equipment replacement, these operations are likely to result in some contamination of the liquid metal with oxygen or water vapor. If precautions are taken to reduce contamination while the system is opened, repairs can be made a number of times before the contamination becomes serious.

If necessary, the liquid metal charge can be filtered at low temperature to remove some of the oxygen absorbed while the system was open. Contamination with oxygen to a high degree would present an extremely difficult recleaning problem.

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*Uranium from Phosphate Rock**

ALTHOUGH the amount of uranium present in most marine phosphate rock is on the order of four-tenths to two-tenths of a pound per ton of rock, the Atomic Energy Commission has been sponsoring studies aimed at developing a method for recovering these small quantities. The importance of this objective becomes apparent when one considers the large tonnage of phosphate rock mined annually. The uranium in this rock has not been recovered but has been distributed over America's agricultural lands.

When preliminary studies indicated that recovery from wet-process phosphoric acid might be easiest, research was aimed in that direction. It became known that most of the uranium in the phosphate rock was dissolved when rock was treated with an excess of sulphuric acid. When the slurry was filtered, the bulk of the uranium was found in the phosphoric acid.

There was one major drawback to development of a uranium production method based on wet-process phosphoric acid. Only about 1,000,000 tons of phosphate rock per year were used in commercial plants to make wet-process acid. As the tonnage of rock used to make normal superphosphate is much larger, research continues to seek a means of recovering uranium from normal superphosphate.

By the summer of 1950, a number of recovery schemes had been examined and several looked worthy of study on a larger scale. One of these was scheduled for pilot-plant operation and a unit was built. It recovered uranium with acceptable efficiency. When it became apparent that this small unit would not give all the answers to the technical and economic questions that arose, a larger unit was built in cooperation with a major commercial producer of phosphoric acid. This larger unit has been operating for several weeks. Data being developed in Florida will guide us in reaching decisions on methods to use to recover uranium in full-size plants.

At the same time that this pilot plant is in operation, a full-scale production plant is now under construction to recover uranium from the wet-process phosphoric acid made by one of the nation's largest producers of phosphate chemicals. This unit will use a uranium production process that has proved eminently successful in semi-plant-scale operations worked into the regular manufacturing process of this particular plant.

Other pilot plants are in operation to develop design data for full-scale plants. Research for new and better recovery methods goes forward.

* From a speech by Sheldon P. Wimpfen, Division of Raw Materials, U. S. AEC, at Atlanta, Ga., Nov. 14, 1951.

Activities Induced in Common Foods by Thermal-Neutron Exposure

Results of subjecting 15 representative foods to cyclotron bombardment confirms the calculations which show that food found in unbroken containers after an atomic explosion will be safe to eat

By DOROTHY C. PETERSON, S. H. WEBSTER, and E. J. LILJEGREN
National Institute of Arthritis and Metabolic Diseases
National Institutes of Health, Public Health Service
Bethesda, Maryland

A QUESTION being discussed in many quarters these days is whether foods that "survive" an atomic-bomb detonation will be fit for human consumption in view of possible radiation hazards.

Radioactive materials that fall on foodstuffs may produce an activity that results in only surface contamination. In some instances, this activity can be removed by surface treatment. Surface treatment, however, is ineffective against the activity that may be induced throughout the entire volume of a food (and its container, if it has one) by the neutron flux associated with the detonation. The experiments described below concern the latter activity.

Calculations of induced activities anticipated following a nominal burst indicate the health hazard from the consumption of foods in containers not destroyed by blast is negligible (*1*). To check the validity of these calculations, which neglected elements present in small quantities, fifteen representative foods were exposed to slow neutrons to determine the resulting induced radioactivities.

In general, of the elements in most foods, only sodium, potassium and phosphorus are in high enough concentration and have cross sections sufficiently large to yield radiopactive products of practical importance. They yield, upon neutron bombardment, 14.8-hr Na^{24}, 12.4-hr K^{42}, and 14.3-day P^{32}.

Chemical analyses for these elements were made on samples of all foods tested.* With canned foods, duplicate cans of the same lot number were secured. One was used for analysis, the other for bombardment. All other foods were divided into two portions, one portion used for analysis, the other for bombardment.

TABLE 1—Analyses of Foods Used in Bombardments

Food	*Mg/100 gm of edible portion*		
	Na	*K*	*P*
Apple, raw*	2	125	12
Beans, baked, canned	490	255	88
Beer, canned	5	26	17
Bouillon cubes, in tinfoil	23,000	1,400	600
Bread, baked	465	110	25
Butter, dairy, salted	626	22	10
Cereal, whole wheat, uncooked	25	340	330
Cheese, American Cheddar	490	60	66
Chocolate, bitter	9	165	27
Eggs, whole, raw	116	126	187
Fish, tuna, canned	302	147	166
Ham, smoked, partially cooked	929	254	149
Milk, evaporated, canned	92	260	126
Peas, canned	300	57	41
Spinach, canned	513	163	14

* Values from literature

The samples used for analysis were ashed in a muffle furnace at 600° C. Aqueous solutions of the residues were analyzed using the uranyl acetate method (*2*) for sodium, the chloroplatinic acid method (*3*) for potassium, and the Fiske and Subbarow method (*4*) for phosphorus. The results of the analyses are shown in Table 1.

The food samples, together with gold-foil monitors and standard solutions of Na_2CO_3, K_2CO_3 and $Mg_3(PO_4)_2$, were bombarded with cyclotron neutrons† moderated with about four inches of paraffin. Three bombardments were made, the number of slow neutrons ranging between 2×10^{13} per cm^2 and 3.7×10^{13} per cm^2, as determined with the gold-foil monitors. The foils indicated that the number of neutrons was substantially constant throughout the paraffin enclosure.

At the end of each bombardment, the food samples were removed and

* Apples were not analyzed.

† Through the cooperation, of Dr. Merle A. Tuve, the cyclotron at the Carnegie Institution of Washington was used for all food bombardments.

TABLE 2—Monitoring Data for Bombarded Foods

	Total flux $n/cm^2 \times 10^{-13}$	*Time from bombardment (min)*	*Millirocntgens per hour* (*MX-6*) *Gamma only*	(*SU-1B*) *Beta gamma*	(*SU-1B*) *Gamma only*
Apple, whole (100 grams)	2.7	30	0	0	0
Beans, baked, No. 2 can, filled	3.7	75	19	70	60
Can, empty	"	150	28	65	38
Beans, (500 gm)	"	150	3	6	5
Beans, baked, brown glass jar, filled	3.7	75	65	105	95
Jar, empty	"	150	70	95	70
Beans, (500 gm)	"	150	4	6	5
Beer, 1 can, filled	2.7	20	40	85	50
Can, empty	"	60	..	80	50
Beer, (345 gm)	"	60	..	0	0
Bouillon cubes, in tin foil, 1 box of 12	"	20	40	155	107
Bread, (9 gm) $1\frac{3}{4} \times 1\frac{3}{4} \times \frac{3}{4}$ in.	"	20	0	5	2
Butter, ($\frac{1}{4}$ lb)	"	20	0	10	7
Cereal, (15 gm)	"	20	0	2	2
Cheese, (21.5 gm) $1 \times 1 \times 1$ in.	"	20	0	4	3
Chocolate, 1 oz square	"	20	0	2	2
Eggs, in shell, one	"	20	0	2	0
Fish, tuna, 1 can, filled	3.7	80	30	115	70
Ham, $2 \times 2 \times \frac{1}{2}$ in.	"	80	..	17	6
Milk, 1 can, filled	2.7	20	9	50	30
Can, empty	"	60	..	45	25
Milk, (408 gm)	"	60	..	2	2
Peas, (100 gm)	2.0	..	..	..	..
Spinach, No. 2 can, filled	2.7	20	16	95	45
Can, empty	"	60	..	80	35
Spinach, (456 gm)	"	60	..	5	4

TABLE 3—Observed and Calculated Activity for All Foods Bombarded

	Microcuries per 100 grams bombarded food					
	Time from end of bombardment					
	0 hours		*40 hours*		*100 hours*	
Food	*Obs.*	*Calc.*	*Obs.*	*Calc.*	*Obs.*	*Calc.*
Apple	0.13	0.03	....	....	....	....
Beans, baked (from can)	2.4	2.4	0.38	0.38	0.03	0.03
Beans, baked (from jar)	2.2	2.4	0.32	0.38	0.02	0.03
Beer	0.04	0.04	....	....	....	....
Bouillon cubes	107.4	111.0	16.3	16.7	1.1	1.0
Bread	3.5	2.3	0.56	0.37	0.04	0.02
Butter	3.6	3.0	0.52	0.44	0.04	0.03
Cereal	1.0	0.31	0.05	0.05	0.02	0.02
Cheese	2.6	2.4	0.5	0.4	0.06	0.03
Chocolate	0.7	0.13	0.08	0.02	0.02	....
Fish, tuna	3.8	1.6	0.59	0.27	0.09	0.03
Egg	0.7	0.7	0.12	0.12	0.02	0.02
Ham	10.8	4.6	1.7	1.0	0.13	0.05
Milk	0.6	0.6	0.09	0.09	0.01	0.01
Peas	2.4	2.2	0.4	0.35	0.03	0.03
Salt (plain)	162.0	189.0	25.0	30.0	1.9	1.6
Salt (iodized)	154.0	189.0	25.0	30.0	1.9	1.6
Spinach	2.2	2.6	0.33	0.37	0.03	0.02

monitored individually with ionization-chamber survey instruments. The monitoring data are presented in Table 2. These data are presented only as sample guides and have not been normalized with respect to neutron flux and time of observation. An inspection of the table shows that, in general, the container contributes a large fraction of the activity present.

Representative samples of each food were homogenized, weighed into aluminum pans and dried under infrared lamps. Aliquot portions of the standard solutions were pipetted into the counting pans and dried. Counts were made on all samples as soon as possible and repeated twice daily for four days. No corrections were made for self-absorption since none of the samples counted was sufficiently thick to reduce the beta count by any substantial amount. Counts were made also on some of the food containers, using either the entire container or a weighed portion. A G-M tube with a mica end window of less than 2.0 mg per cm^2 equivalent thickness and a scaling circuit were used.

Results

Because of the nearly equal half-lives of Na^{24} and K^{42}, a three-component analysis of the observed decay curves was not made. Instead, the observed activities were compared with those calculated from the measured activities of the standard solutions and the results of the chemical analyses.

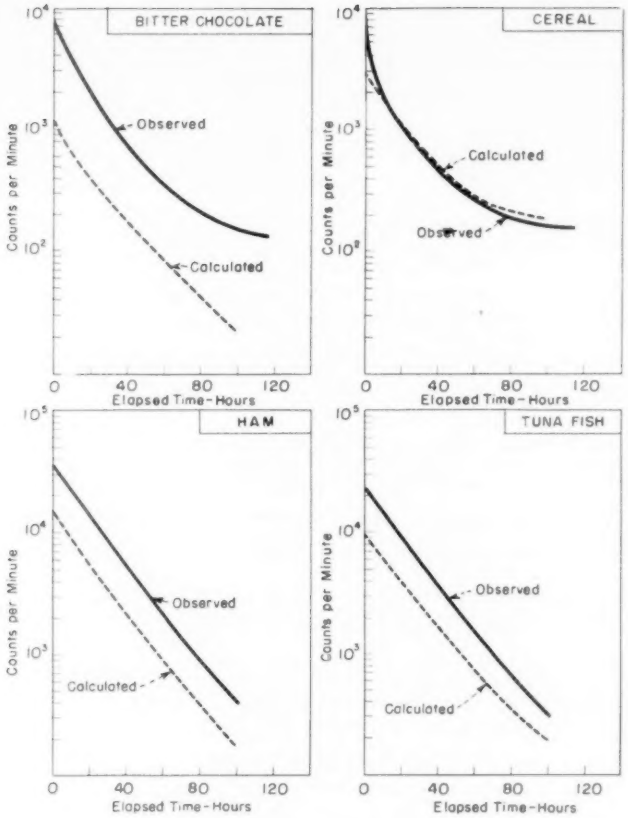
Using sodium as an example, the contribution of each element to the total count is determined by the expression

$$(\text{cpm})_{Na} = C_{Na} e^{-\lambda_{Na} t} (\text{conc.})_{Na}$$

The constant, C, depends upon the neutron flux, capture cross section, and the counting geometry.

If these factors are held constant, the value for C can be evaluated for each of the three elements from the counts obtained from the standard solutions. Knowing these values and the concentration of each element in the food, it is possible to compute the expected contribution of each to the total count.

Table 3 shows the observed and calculated activities for the foods used in this study. For ease in comparison, all values have been normalized to 10^{13} neutrons per cm^2. In most cases, the



Observed and calculated decay curves for chocolate, cereal, ham, and tuna fish

TABLE 4—Microcuries of Beta Activity per Kilogram Body Weight, Based on a 70-Kilogram Man Ingesting 100 Grams of Food

	μc/kg	
	Distance from ground zero	
	1,700 feet 5×10^{11} *n/cm²*	*2,600 feet* 5×10^{10} *n/cm²*
Apple	8×10^{-4}	8×10^{-6}
Beans, baked	1.6×10^{-3}	1.6×10^{-4}
Beer	3×10^{-5}	3×10^{-6}
Bouillon cubes	6.7×10^{-2}	6.7×10^{-3}
Bread	2.4×10^{-3}	2.4×10^{-4}
Butter	2.4×10^{-3}	2.4×10^{-4}
Cereal, whole wheat	3×10^{-4}	3×10^{-5}
Cheese	1.8×10^{-3}	1.8×10^{-4}
Chocolate	5×10^{-4}	5×10^{-5}
Egg	5×10^{-4}	5×10^{-5}
Fish, tuna	2.5×10^{-3}	2.5×10^{-4}
Ham	7.4×10^{-3}	7.4×10^{-4}
Milk, evaporated	4×10^{-4}	4×10^{-5}
Peas, canned	1.9×10^{-3}	1.9×10^{-4}
Salt	0.102	1×10^{-2}
Spinach, canned	1.3×10^{-3}	1.3×10^{-4}

agreement between the observed and calculated values are within the limits of error expected from the chemical analyses and sampling variations.

From the sets of curves shown on this page, it can be seen that four of the foods, chocolate, whole-wheat cereal, ham, and tuna fish, show marked differences between the observed and calculated values.

Both ham and tuna fish have a high sodium content and, since each show a typical Na^{24} decay curve, it is probable that the lack of agreement is due to sampling variations rather than to a contribution from some other element.

Chocolate has a high potassium content with little sodium and phosphorus, but the decay curve is not typical of K^{42}. The observed activity throughout the counting period was considerably greater than would be expected from the potassium content. Trace elements in chocolate include appreciable quantities of copper and manganese, each of which has a substantial cross section for neutron capture.

The initial activity of the cereal was considerably higher than the calculations predicted, but agreement was good after 40 hours. Extrapolation of the first two points on the decay curve indicated an element with a half-life of about three hours. Since manganese was found in a qualitative test, it seems probable that the lack of agreement is due to the presence of 2.59-hr Mn^{56}.

Discussion

From earlier data, the potential hazard due to ingestion of these typical foods can be evaluated. Marinelli (*5*) has calculated the amount of radioactive materials required to produce a tissue dose of 0.1 rep during the first 24 hours after administration. The figures of interest to this study are:

Na^{24}:	1.3 μc/kg of body weight
K^{42}:	1.9 " " " "
P^{32}:	2.4 " " " "

Table 4 shows the activities to be expected due to the ingestion of 100 grams of food by a 70-kg man. These calculations are based on 5×10^{11} neutrons per cm², which is the number of slow neutrons anticipated (*6*) at 1,700 feet from the point of detonation of a nominal bomb. The number of neutrons decreases rapidly with distance and at 2,600 feet is only 5×10^{10}

per cm². At points within the radius of 1,700 feet, the number of neutrons increases rapidly as the distance decreases, but in this area food will almost certainly be destroyed by blast and fire.

The values in Table 4 indicate that as far as induced activities are concerned there is a large margin of safety in consuming any reasonable amount of food. It is known that organic compounds are altered (7) by high-energy radiations and it is possible that toxic breakdown products might be formed. However, the yield from these reactions is generally low and it is doubtful that any toxic compound can be formed in dangerous concentrations.

No separate determinations of C^{14} from the $N^{14}(n,p)$ reaction were made, but calculations show that the contribution of C^{14} to the total activity will be very small and this will have a relatively short biological half-life (8).

The present work takes no account of surface contamination with radioactive materials. This will not affect packaged foods if care is used in opening the containers. In some cases, unpackaged foods might be consumed after removing the surface contamination, but, in other cases, the food might be completely unfit for human consumption.

Conclusions

In general, it appears possible to calculate neutron-induced radioactivities in foods from the sodium, potassium and phosphorus contents. However, other elements are sometimes present in sufficient concentrations to increase the activity significantly over that calculated.

The radioactivity induced in foods at a distance of 1,700 feet is so low that the ingestion of any reasonable amount will give a radiation dose that is insignificant compared to presently accepted tolerance doses.

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SECRECY in NUCLEAR ENGINEERING

One of the most perplexing problems in our atomic energy program is how to develop strength in a vital effort without lending help to unfriendly nations.

A continuing decision which must be made is where to draw the line on secrecy.

Here the man who is closest to this problem questions whether we can effectively compete in the world atomic race unless we let down the barriers of secrecy.

By J. G. BECKERLEY
Director of Classification
U. S. Atomic Energy Commission
Washington, D. C.

THE CURRENT international situation in atomic energy can be described, with some simplification, as an international competition in the production of fissionable materials and military devices using these materials. As one of the competitors, we must find out not just solutions to a wide variety of nuclear engineering problems in producing fissionable materials and devices, but we must find out the *best* solutions to these problems—at least the solutions must be *better* than those developed by our competitor. And, we must find these solutions more *quickly* than our competitor.

It is not my intention to discuss the origins of the current international competition for atomic weapons, military reactors and nuclear fuels. However, I should like to emphasize it *is* a competition. The United States and the western allies are not co-partners in a monopoly in this field any more than they are in any other field of modern armaments. We must compete with the USSR and her satellites in manufacturing atomic devices just as we must compete in manufacturing jet engines and guided missiles.

The fact that we are in an entirely competitive situation bears a close relation to my subject since it is definitely debatable whether we can meet the challenge of competition without altering the present conditions of

secrecy in our atomic energy enterprise.

In this article, I plan to discuss the current status of secrecy in nuclear engineering information. At the same time, I wish to point out what I believe to be a distinct possibility, and a possibility which the Commission is determined to avoid, namely, that we may fail to meet with sufficient superiority the challenge of the USSR in this field unless we are able to take a less rigid approach in determining the extent secrecy is necessary and the degree of protection which must be afforded the information to be concealed.

It is debatable whether we can afford to deny ourselves the assistance of the engineering community at large by keeping a substantial part of our technology, including obsolescent technology, under wraps.

It is debatable whether we can afford to handicap those engineers who are working on many atomic energy projects by insulating them in many respects from the rest of the engineering profession.

It is debatable whether we can always afford the expense in manpower and money of many of the security practices presently used in atomic energy projects.

And, I hasten to add, there is a peculiar difficulty in removing unnecessary secrecy—the difficulty of convincing the public, the press, and the Congress that the secrecy is unnecessary and hampering. Public discussion of the bases for believing certain information need not be closely held might "tip our hand."

Now let us get away from broad generalizations and consider facts. What is the current situation in nuclear engineering? Which areas of information are published and which are concealed? Where can we anticipate real engineering interest and assistance if more information is declassified or if circulation is liberalized by removal of certain security requirements?

Starting at the base of the atomic energy project, we find the following:

1. Raw materials

Exploration and mining engineering is almost entirely an "open" field. Instrumentation is published; mining concerns have essentially no problems of restricted data. There would be little gain in declassifying the relatively small volume of classified information in this field. Most of the latter concerns over-all estimates of ore reserves and similar information.

2. Ore concentration and beneficiation

This is principally "open," except that we become increasingly sensitive about publishing process details as the uranium concentration becomes lower. This latter illustrates the typical dilemma. We would undoubtedly benefit by easing up in the field of low-grade ore concentrating. However, it is also clear that "inimical interests" would likewise benefit. Whereas more liberal security requirements in the Atomic Energy Act might permit broader industrial participation without appreciably increasing the probability of leakage, declassification of really useful low-grade ore processes might not be worth the risk of assisting potential enemies.

3. Feed materials

Here uranium concentrates are refined and converted into uranium metal or hexafluoride. Metal and "hex" have been produced for nine years by a number of chemical processing firms in efficient and economical means. Almost all process information is classified in the feed materials chain; however, associated instrumentation, analytical techniques, health problems, basic chemistry are declassified. Removal of process information from secrecy or liberalizing security requirements would probably have a relatively secondary effect, although it must be conceded that a more "open" project might encourage additional good new ideas and result in lower costs or greater efficiency.

4. Production of fissionable materials

Separation of uranium isotopes involves mechanical and chemical engineering. As this is technology, only fragmentary declassification is practiced. Barrier production and electromagnetic separating equipment are really the only features of separation work involving "nuclear" engineering. (In fact, it is debatable whether barrier technology should be considered to be "nuclear" engineering, even though it is essential to one process for producing nuclear fuels.) The wartime gaseous diffusion plant has been enlarged and improved by an aggressive and competent industrial company.

Here again it is difficult to assess the advantages which might accrue if a more liberal declassification or security policy were adopted. It is clear that in the long run, we might avoid the ever-present risk of inbreeding and its attendant high mortality rate for really "new" ideas. It is also clear that "new" ideas are not particularly welcome in any case, since the magnitude of plant investment is so large as to preclude any drastic process change unless undertaken over some years.

Production of plutonium by nuclear reactors is the heart of nuclear engineering. It is in many respects a new technology. To date we have permitted *integrated* releases of information only on certain low-power research reactors. We hope to supplement this in the near future. On other reactors, the release has definitely been fragmentary. Instrumentation and health physics are "open" fields. Control techniques are almost entirely in the open. Beyond these, most information is classified. Certain reactors, e.g. the Brookhaven graphite-uranium reactor, are "semi-open" with principal sensitivity centered in the fuel elements.

Reactor technology has such a large variety of design parameters that I believe a substantial liberalization of dissemination will be necessary if we are to profit by the immense reservoir of ideas and "know-how" of the U. S. engineering community. I will discuss this further below. Suffice it to point out that there is not now available to the engineering community at large sufficient information to permit realistic, detailed and complete consideration of the technical problems of production or power reactors.

The chemical processing problem associated with reactor fuels is in somewhat the same state, although the basic chemistry of all the important materials has been released as well as the techniques of handling "hot" materials. No process, even obsolete, has been released for decontaminating nuclear fuels. No detailed cost information is available on any of these activities. The Commission is anxious to foster broader participation in the reactor program. Whether this may be accomplished, as at present, by "classified" participation (e.g. the current power-reactor studies by cer-

tain industrial concerns) or whether further declassification is needed, remains to be seen.

5. Production of atomic weapons

The physics of fast chain reactions has not been released, although certain theoretical methods and mathematical techniques of broad applicability have been declassified. Information in this field has to be quite "basic" before it is releasable. Some real advantages might result from liberalizing secrecy practices in this field, since there is the continual danger that new ideas might make our stockpile obsolete. We plan a skeptical inquiry into the question whether certain almost "rock-bottom" ideas (not devices) can be discussed more openly or be less "compartmentalized" in the hope of more rapid development of new weapons.

It is apparent from the above that most of the classified nuclear engineering information is in the reactor field and that a liberal secrecy policy in this field is most likely to hasten our program. This is also the field of greatest nonmilitary interest, since reactor-produced power has a broad potential market. A manufacturer of atomic weapons would, we trust, have only one customer. On the other hand, a vendor of power, with by-products of radioisotopes and fissionable materials, could conceivably conduct his business on a basis more or less similar to a conventional industrial enterprise. Of course, whether he could stay in business or not would depend, in addition to his own efforts, on the economics of the mining and feed materials chain as well as on the marketability of his by-products. (All or part of the by-product fissionable material might be a government purchase.)

The current reactor situation may be summarized by listing the approximate order of current expenditures in the reactor field: (1) reactors for producing fissionable materials; (2) reactors for producing power for propulsion of military vehicles; (3) experimental reactors for use in developing new reactors; (4) reactors for general power production purposes. This order ultimately may be affected by the great political problems attendant in any use of atomic weapons. Certainly if we find it politically difficult to use atomic weapons in military operations, it will follow that the mobile power-producing reactor will become relatively more important. This point is brought up since there are occasional tendencies to underemphasize the military significance of the reactor program other than as a fissionable material producer.

As long as the power reactor program retains its present lower priority, we will probably not be too wrong in retaining the boundaries of secrecy about where they are today. However, there is a real risk in this priority. The atomic energy project is rapidly becoming a burden to the electrical power producers, so much so that we may well have an adverse effect on other defense efforts. We are becoming more of a nuisance in this respect with each plant, for it is no secret that we operate endo-ergic plants. One of these days we will be on the spot unless our reactors can generate power.

The power reactor has an immense variety of possibilities. Consider the almost infinite variety of alloys, mixtures, lattices, solutions, slurries of nuclear fuels. To explore even a part of this array of possibilities for reactor designs requires considerable trained manpower. The training should be accomplished in the universities and engineering schools if for no other reason than that it is cheaper and less wasteful of time. With a fragmentary release of technical information, it is doubtful whether an aspiring nuclear engineer can secure a sufficiently integrated and practical training unless he works on an AEC project (and then he should already have been trained).

Just imagine an aeronautical engineering graduate student trying to study aircraft design having access only to the Wright brothers' data plus fragmentary information on later aircraft. It is nearly that bad in nuclear reactor engineering since the student only has access to information on a very few obsolete devices and a few bits and pieces of information on newer developments.

Likewise imagine Boeing trying to compete with Lockheed in a situation where Boeing has access to the latest information on aircraft design while Lockheed has only the Wright brothers' data plus general qualitative statements on all post-Kitty Hawk developments. This would scarcely be a competitive situation. We certainly have comparable situations today on the atomic energy project, situations where competition is essentially nonexistent. (I mean this as no criticism of firms involved in the atomic energy program since many of the monopolistic features of the atomic energy project are primarily derivable from the Atomic Energy Act itself as well as the current swift-moving international situation.)

The Commission has already moved in the direction of alleviating this situation. The power industries' participation in studies of power and plutonium-producing reactors will certainly increase competitive possibilities. I believe this is essential to a strong atomic energy effort. It is probably the only way that our "latest and, we hope, best" ideas can be discussed in any broad group. However, I am equally certain these industries have experienced considerable hardship in view of the newness of the nuclear engineering field. And, they have undoubtedly found the field new not just in the time sense, but new to most of their engineers since, prior to the study, they could not study any similar declassified information.

To sum up then, we note

1. A competitive international "atomic" situation demands a broader national participation than presently possible.

2. Information on obsolete plants and processes must soon be considered to have greatly diminished security value.

3. A healthy national nuclear engineering "know-how" may not be developed by publication of a fragmentary collection of odd technology.

4. The present situation is not necessarily a healthy situation.

5. The bases of our secrecy policy must be continually and skeptically reviewed.

In a competition, as in other activities, it does not matter who "gets there." What matters is who gets there "fustest with the mostest." Under the handicaps of rigid secrecy practices, where urgent problems may be attacked only by a "chosen few," we might, to paraphrase the staunch soldier, arrive the "latest with the leastest."

* * *

This article is based on a talk before the Institute of Radio Engineers, Dec. 3, 1951, at Upton, N. Y.

Consultants on Isotope Techniques

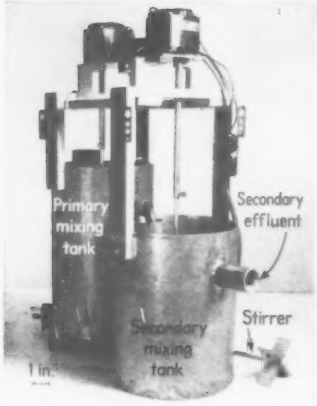
Increasing use of isotopes makes useful an up-to-date list of available consultants. These are additions to the July list.

Here is the first addition to NUCLEONICS' July, 1951, list of consultants on isotope techniques. To maintain the usefulness of the list, names of additional consultants will be added periodically.

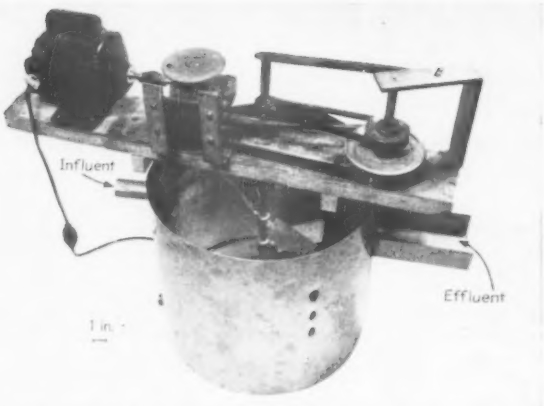
As in the previous list, individuals are listed according to geographical location, with their fields of specialization indicated.

Arrangements for services should be made directly with the desired consultant. His availability for consultation will be limited by the demands of his regular work.

	Physics	Biology and Medicine	Instruments	Chemistry	Health Physics	Industry
CALIFORNIA						
Richard I. Condit, Broadview Research & Development, P.O. Box 1093, Burlingame	✓		✓		✓	✓
Allen M. Goldstein, Technical Associates, 3730 San Fernando Road, Glendale 4	✓			✓	✓	✓
J. D. Graves, Broadview Research & Development, P.O. Box 1093, Burlingame	✓		✓	✓	✓	✓
M. E. Morton, School of Medicine, U. of Cal. Medical Center, Los Angeles 24		✓		✓	✓	✓
DISTRICT OF COLUMBIA						
Maxwell Dauer, Medical Research and Development Board, Office of the Surgeon General, Dept. of the Army, Washington 25		✓	✓		✓	
ILLINOIS						
William C. Cleveland, Jr., Radiation Counter Laboratories, Inc., 5122 W. Grove St., Chicago 8			✓			
Keith Johnson, Radiation Counter Laboratories, Inc., Chicago 8			✓			
Anthony Kriz, Testing Division, City of Chicago, 3100 South Sacramento Ave., Chicago 23	✓		✓			✓
Bernard Ross, Radiation Counter Laboratories, Inc., Chicago 8	✓		✓			
Ernest H. Wakefield, Radiation Counter Laboratories, Inc., Chicago 8	✓		✓			
Raymond L. Weiland, Radiation Counter Laboratories, Inc., Chicago 8		✓			✓	✓
MARYLAND						
Charles H. Voelker, Physics Dept., Washington College, Chestertown	✓				✓	✓
MASSACHUSETTS						
Robert P. Epple, Tracerlab, Inc., 130 High Street, Boston 10				✓		
Melvin Fields, Tracerlab, Inc., 130 High Street, Boston 10				✓		
W. F. Goodyear, Tracerlab, Inc., 130 High Street, Boston 10			✓			
George M. Kavanagh, Tracerlab, Inc., 130 High Street, Boston 10				✓		
Wendell C. Peacock, Tracerlab, Inc., 130 High Street, Boston 10	✓	✓				
John C. Pennock, Tracerlab, Inc., 130 High Street, Boston 10			✓			
MISSOURI						
M. Ter-Pogossian, School of Medicine, Washington University, St. Louis 10	✓		✓		✓	
MONTANA						
Norman J. Holter, Medical Physics Laboratory, Holter Research Foundation, Inc., Helena		✓				
NEW JERSEY						
Charles E. Crompton, Radioactivity Division, U. S. Testing Co., Inc., 1415 Park Ave., Hoboken				✓		✓
J. L. Zar, 447 Central Ave., Orange	✓		✓			
NEW YORK						
Peter H. Bosch, Atomic Associates Inc., 534 W. 124th St., N. Y.	✓	✓		✓	✓	✓
OHIO						
John R. Bradford, Radioisotopes Laboratory, Dept. of Chem. and Chem. Eng., Case Institute of Tech., University Circle, Cleveland 6				✓		✓
Otto Glasser, Dept. of Biophysics, Division of Med., Cleveland Clinic, 2020 E. 93rd St., Cleveland 6		✓			✓	
PENNSYLVANIA						
A. V. Grosse, The Research Inst. of Temple U., Philadelphia 22				✓		✓
A. D. Kirshenbaum, The Research Inst. of Temple U., Philadelphia 22				✓		✓
M. V. Scherb, Atomic Associates Inc., Land Title Building, Philadelphia 10		✓	✓	✓	✓	✓
TEXAS						
George W. Cox, State Health Officer, Texas State Dept. of Health, Austin 1					✓	
WASHINGTON						
Norman D. Lee, Dept. of Medicine, School of Medicine, U. of Washington, Seattle 5		✓				



1 Tap water, local clay slurry, sample radioisotope and lime are mixed in primary tank; sodium silicate is added as mixture passes to secondary tank. Alum is added near outlet



2 Flocculation (coagulation) tank is equipped with motor-driven stirrer consisting of three pairs of blades inclined at 45 degrees. These provide a peripheral velocity of about 0.83 ft/sec. The coagulants added in the mixing tanks react with the contaminants, forming flocculant particles that increase in size. Detention of 45 min is obtained with a flow of 1,000 liters/day

PICTURE FLOW-SHEET shows pilot plant at Oak Ridge National Laboratory that uses conventional water-treatment processes for

Removal of Radioactive Waste

By CONRAD P. STRAUB*

Health Physics Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee

TREATMENT of large volumes of raw water and industrial wastes containing low concentrations of solid materials is a routine matter for sanitary engineers. Since liquid radioactive wastes are similar in all respects except radioactivity to industrial wastes, sanitary-engineering procedures are being used to develop techniques for the treatment of these wastes. Also, the effectiveness of existing water, sewage and waste treatment processes for the removal of radioisotopes from waste liquids is being evaluated.

As part of this program, the Radioactive Waste Disposal Research and Development Section, Health Physics Division, Oak Ridge National Laboratory, designed and fabricated the pilot plant described here. Experimental results obtained with this apparatus, together with additional techniques and procedures that have been applied successfully by others in the field, are given in this article.

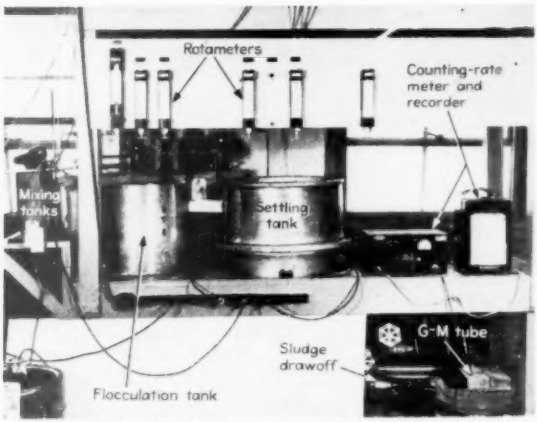
Pilot plant. The equipment is similar in design to that now used for treatment of potable and industrial waters. Municipal water-works usually include facilities for chlorination and storage following the filtration stage, however.

The pilot plant has a design capacity of approximately 1,000 liters per day. It includes facilities for mixing, coagulation or flocculation, sedimentation, and rapid sand filtration. Stainless steel is used for the tanks to permit easy decontamination. Constant-head tanks are used to feed tap water, radioisotope solutions, lime and alum into the units. A Harvard-type roller displacement pump is used to feed clay slurry and sodium silicate into the system. Final effluent from the filters is collected in carboys, and the residual radioactivity and rate of flow are measured.

Filter backwashing. As in conventional water works, the filters used in the pilot plant are backwashed. Here, however, backwashing serves to remove radioactive materials from the filter bed, in addition to the usual removal of accumulated material, carried over from the settling basin, that blocks flow through the filter.

To backwash a filter, the flow to the filter is cut off and the liquid level in the filter allowed to drop to just above

* Sanitary engineer, U. S. Public Health Service.



3 Settling basin is 55-gallon drum. Here radioactive materials adsorbed or entrained in the floc particles are removed by settling. Sludge collects in hopper at bottom of basin; liquid effluent is monitored for radioactivity. Detention time in the settling basin can be varied from 2 to 4.5 hr

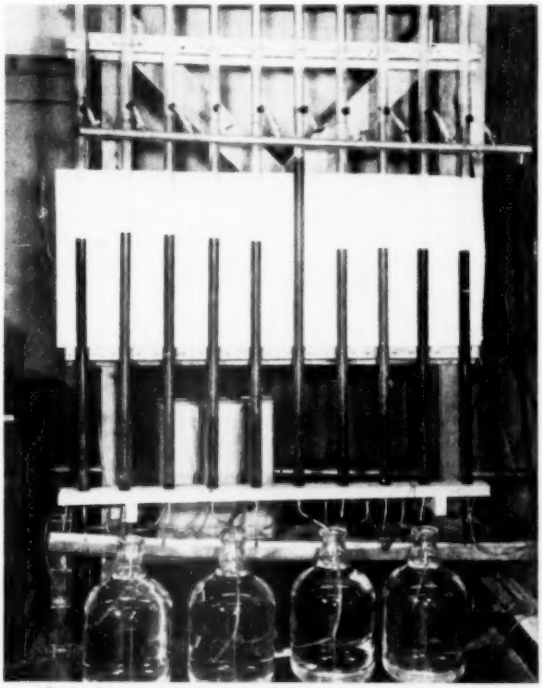
4 Flow-proportioning and sampling tank has sawtooth weir with one of 72 teeth blocked so that sample proportional to flow can be obtained. Settling-tank effluent is pumped from this unit to overhead orifice-feed tank above filters

from Water

the sand surface. Potable tap water is then run in slowly from the bottom to expand the bed and to permit washing. As the sand bed expands, the flow of backwash water is increased until the filter medium is expanded by 50%. In the flow sheet, filter 6 is being backwashed, and the expanded volume is visible.

Six inches above the expanded medium, the waste backwash water flows through an outlet to a manifold where it is collected, its volume noted, and the radioactivity measured. The accumulated material from the filter is carried out with the waste water because its specific gravity is much less than that of the filtering medium.

Laboratory-scale tests. Before a run is made in the pilot plant, optimum chemical dosages for efficient and economical operation have to be determined. Cut-and-try procedures have



5 Bank of ten Lucite laboratory filter columns are fed from feed tank directly above them. Overflow from tank goes back to preceding tank. The first filter (left) contains a local filter sand; filters 2 through 8 contain synthetic mixtures of sand (uniformity coefficient 2.0, effective sizes from 0.35–0.95 mm at 0.1 mm intervals); filters 9 and 10 contain Anthrafilt, an anthracite-coal filtering medium (effective sizes, 0.75 and 1.68, uniformity coefficients 1.81 and 2.0, respectively)

to be used to determine dosages for each water or waste studied.

Different combinations of coagulating chemicals may be investigated simultaneously in the device (*1*) shown in Fig. 1. Ten jars have stirrers connected by a chain drive. A gear-shift-controlled drive on the motor permits rapid mixing at a peripheral speed of 2.83 ft/sec and slow mixing at a peripheral speed of 0.71 ft/sec.

Treatment Methods

Of the methods known to sanitary engineers and chemists for treating domestic and industrial wastes the following have been suggested as possible modes of attack in solving problems incident to the treatment and disposal of radioactive wastes: evaporation, carrier precipitation (coagulation), ion exchange (natural clays and synthetic resins), biological processes, metallic displacement or scrubbing, sand filtration, crystallization, solvent extraction, electrolytic separation, differential volatility, and electrodialysis. These specific treatment methods, as they apply to the removal of radioactive materials, will be noted below with emphasis on the treatment techniques tried in our laboratories and some of the preliminary results available.

Evaporation. For the concentration of large volumes of wastes containing small amounts of radioactive substances, evaporation, although expensive, will remove practically all of the activity from the liquid fraction and will concentrate that activity in the solid residue or slurry. To permit disposal as a solid residue or slurry, and to reduce the amount of space required for storage of liquid radioactive wastes, evaporation is desirable.

In June, 1949, a waste evaporator was put into operation at Oak Ridge National Laboratory to concentrate the radioactive components of the radiochemical waste for storage. The evaporator is a simple, pot-type, internal-steam-coil heated unit housed in a shielded concrete building. It has a design capacity of 300 gal/hr. Decontamination factors (influent activity divided by effluent activity) of 10^5 have been demonstrated (*2*) with volume reductions of about 60 to 1.

Evaporator foaming is the only serious operating problem so far reported (*2*). The evaporator feed usually contains colloidal particles, dissolved carbon dioxide, organic matter, and salts known to exhibit foaming tendencies. In addition, the *p*H is necessarily high (10 to 11) to prevent distillation of I^{131}, and the feed is evaporated to high salt concentrations. These conditions all contribute to foaming, making the problem difficult to eliminate. At times the volume of foam becomes so great that the evaporator body is filled and the foam overflows into the condensers. This is called evaporator foaming.

Carrier precipitation. Carrier precipitation or coagulation is used extensively in the treatment of many industrial wastes, and has been adapted to the removal of certain radioactive materials. In the removal of As, Sb, Mo, Se, Te, and Ce, coagulation has been applied with varying success; however, with Ru and Pu, removals have been very satisfactory. In many instances coagulation was most effective at high *p*H values, in the ranges normally encountered in chemical softening of water. Studies have been made by our section in which routine and special coagulation techniques have been applied to the removal of specific radioisotopes from "spiked" water solutions.

TABLE 1—Results of Alum Coagulation Studies (*3*)

Element	*Removal (%)*	*Remarks*
I^{131}	Up to 10	Addition of small amounts of Cu, Ag, or C increased removals to 75% .
P^{32}	98+	
Sr^{89}	10	Increasing turbidity from 50 to 1,000 parts per million increased removal efficiencies to 50%
Y^{91}	45	Using NaOH as alkali
	98	Using Na_2CO_3 as alkali
	17–82	For turbidity ranges of 50–1,000 parts per million
Ce^{144}	98	
	70–86	For turbidity ranges of 50–1,000 parts per million
Sr^{90}-Y^{90}	98 for Y	On standing, more of Y daughter formed from Sr.
	10 for Sr	

Using routine alum and lime coagulation, Placak and Lyle (*3*) obtained removals of specific radioisotopes as shown in Table 1. The data shows that alum coagulation was effective for the removal of P^{32}, Y^{91} (when the proper alkaline agent—Na_2CO_3—was used), Ce^{144}, and Y^{90}; the procedure was ineffective for the removal of I^{131}, Sr^{89}, and Sr^{90}.* Essentially similar results were obtained with iron as the coagulant.

Since a study indicated that the number of insoluble phosphates exceeded the insoluble hydroxides, Lauderdale (*4*) carried out experiments in which he employed a modified coagulation technique. Tracer-type runs were made with the isotopes Ce^{144}, Sr^{89}, Y^{91}, Sb^{124}, Zn^{65}, W^{185}, Zr^{95}, and Nb^{95}, which

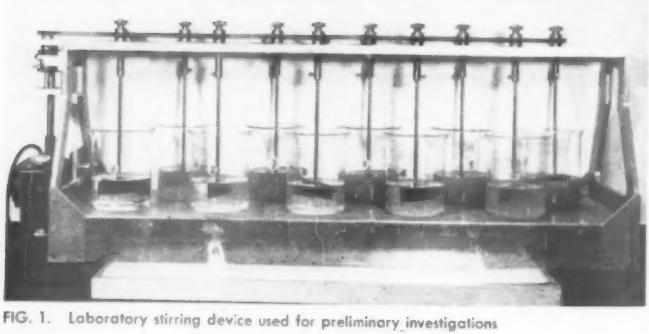


FIG. 1. Laboratory stirring device used for preliminary investigations

* Individual isotopes were treated in same chemical form as listed in Catalog and Price List No. 4, Isotopes Division, U. S. AEC, Oak Ridge, Tenn. P^{32} was initially present as phosphate; Y^{91}, Ce^{144}, Y^{90}, Sr^{89}, Sr^{90}, Zn^{65}, Sb^{124}, and Ru^{106} as chlorides; I^{131} as iodide; Zr^{95} and Nb^{95} as oxalates; and W^{185} as tungstate. Mixed-fission-product wastes contain all of the elements produced in the fission process.

TABLE 2—Results of Phosphate Coagulation Studies (4)

Isotope	*Coagulant*	*mg/liter coagulant*	*Removal (%)*
Ce^{144}	KH_2PO_4	200	99.8
	Na_3PO_4	120	99.9
Sr^{89}	KH_2PO_4	100	81.3
	Na_3PO_4	240	97.8
Y^{91}	KH_2PO_4	100	99.9
Sb^{124}	KH_2PO_4	100	66.1
	Na_3PO_4	120	67.4
Zn^{65}	KH_2PO_4	50	99.6
W^{185}	KH_2PO_4	200	10.7
Zr^{95}	KH_2PO_4	100	99.5
Nb^{95}	KH_2PO_4	100	99.2

TABLE 3—Pilot and Large-Scale Plant Results

Isotope or Test Material	*Treatment*	*Removal (%)*	*Reference*
P^{32}	Coagulation with alum, lime, plus sedimentation	85	(5)
	Above plus filtration	96–98	(5)
I^{131}	Coagulation with alum, lime, sodium silicate, plus sedimentation	<1	(5)
	Above plus filtration	<1	(5)
	Above plus 5 parts per million carbon	15	(5)
	Above plus carbon plus filtration	25	(5)
Mixed Fission Products*	Coagulation with alum, lime, sodium silicate, plus sedimentation	46	§
	Above plus filtration	70–73	§
Mixed Fission Products†	Coagulation with iron plus sedimentation	86	¶
W-6 Waste‡	Coagulation with iron plus sedimentation	29	¶

* Mixed fission products to simulate conditions after a bomb blast but with increased percentages of Ru, I and Sr which are hard to remove.
† Simulates condition after bomb blast.
‡ Dissolver solution represents potential waste from nuclear reactor.
§ Straub, Brockett and Stepp, unpublished data.
¶ Lindsten and Brockett, unpublished data.

These tables and the graphs below and on the next page summarize the results of experiments to date on removal of radioactive waste from water.

were added to distilled water. The experiments were performed at a *p*H of about 11.5 using up to 240 parts per million of Na_3PO_4 or KH_2PO_4 and lime. Some typical results for one-stage batch treatment are shown in Table 2. Essentially complete removals of Ce^{144}, Y^{91}, Zn^{65}, Zr^{95}, and Nb^{95} were obtained by these procedures.

Using the pilot-plant equipment described previously, the writer (5) studied the removal of P^{32} and I^{131} by conventional water treatment processes (coagulation, sedimentation, and filtration). Removals obtained, along with results reported by others, are indicated in Table 3. Figure 2 shows the results obtained in one of the series with I^{131}. In this run, I^{131} was fed continuously along with all the other chemicals indicated in the flow sheet, and simultaneous samples were taken at the time noted at the outlet from the secondary mixing basin, the flocculating tank, the settling tank, and of the filtered effluent. To compare any specific activity in each of the tanks, one would have to offset each of the points noted for a particular time to the right in an amount equal to the actual time of flow in passing through each subsequent unit.

The primary purpose of Fig. 2 is to show that there is negligible removal of the I^{131}. Some may consider that the vertical distance between the points in the early stages of the run represents a degree of removal, but such is not the case since the differences are due to dilutions in activity as a result of passing through a given tank containing non-I^{131} water. In other words, I^{131} equilibrium had not been reached.

Preliminary studies made on the alkaline precipitation of a radioactive waste slurry show that the removal of

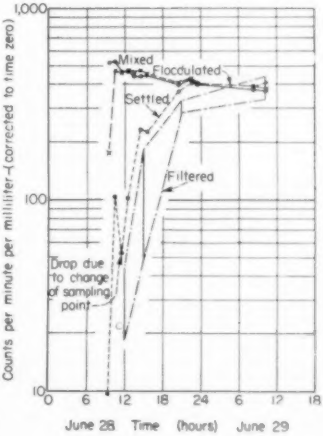


FIG. 2. Iodine-131 activity discharged through various units of pilot plant

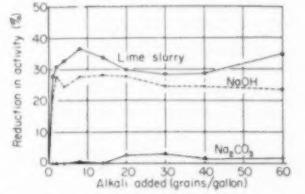


FIG. 3. Removal of metal waste activity by alkaline precipitation

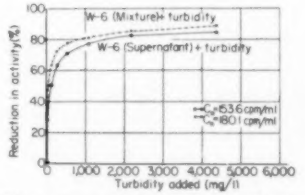


FIG. 4. Removal of metal waste activity by adsorption on clays

radioactive constituents is dependent, among other factors, on the alkaline precipitant used, as shown in Fig. 3. Similar findings are indicated for Y^{91} in Table 1.

Ion exchange (natural clays and synthetic resins). Natural soils and clays are known to take up radioactive elements by adsorption. For the removal of radioisotopes from a mixed-fission-product waste containing about 95% cesium and 4.5% ruthenium, Lauderdale (*6*) used local kaolinitic and montmorillonitic clays as adsorbing agents. Although the dosages of clay required were large, up to 50,000 parts per million, removals of 80 to 85% were obtained. Other soils have been shown to adsorb Pu, Sr, Y, Ce, and Pr. The take up of radioactive material from a waste slurry by clays is shown in Fig. 4 for clay additions in the range of 0 to 4,400 parts per million; reductions in activity up to 88% are indicated.

With the newer high-capacity cationic and anionic synthetic resins, many radioactive elements may be removed from large volumes of dilute wastes. Data released by Ayres (*7*) show that Na, Ba, La, and Ce are removed in cation-exchange columns and that Te, Mo, and Ru are removed in anion-exchange columns. Under suitable conditions Sr, Cs, Ce and other rare-earth materials may be removed by cationic exchangers. Ion-exchange columns may be used for the removal of single radioelements or combinations of certain radioisotopes in dilute solutions which are low in solids. They may also be used as polishing units following the removal of gross radioactive contaminants by coagulation or carrier precipitation and filtration.

Lauderdale and Emmons (*8*) have used a mixed or monobed cation and anion resin bed as the final step in a decontamination unit which included serial passage of the radioactively contaminated solution through beds of steel wool, burnt clay, and activated carbon. This combination of processes resulted in the reduction of the initial concentration from 2.5 $\mu c/cm^3$ to less than 10^{-4} $\mu c/cm^3$.

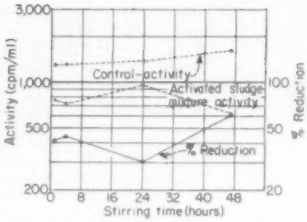


FIG. 5. Removal of metal waste activity by adsorption on activated sludge

Biological processes. Ruchhoft (*9*) has suggested that the activated sludge process be used to adsorb, hold, and remove long-lived inorganic radioisotopes during the development and propogation of cultured floc. Through the use of this process he was able to demonstrate a reduction of about 96% in Pu with single-stage treatment.

Somewhat similar results have been reported (*5*) following preliminary study of the removal of I^{131} by aerated and stirred activated sludge. Studies with a radioactive evaporator waste slurry have shown that up to 60% of the radioactive constituents were removed from the waste by the activated sludge following 24 to 48 hours of stirring. The results of preliminary tests are shown in Fig. 5.

Metallic displacement or scrubbing. This technique, in which one element displaces another in a compound, setting the second element free, has been applied successfully to the recovery of Ru and other substances (*8*).

Sand filtration. Although little information is available on the removal of radioactive substances by sand filtration, unpublished communications indicate that many are removed by adsorption on sand grains. In the sand filtration of pre-coagulated and settled effluents containing P^{32} and I^{131}, experience at ORNL shows that the former was removed to an appreciable extent (Table 3), but that there was no measurable removal of the latter. The P^{32} adsorbed could be eluted from the sand grains by acid and alkali washes.

Crystallization. Studies have been reported (*5*) in which 200-ml samples containing radioactive materials were frozen, and it was found that concentration of the radioactivity had taken place in the core of the ice cake. Crystallization is not restricted to the separation of solids by freezing alone, but may be applied to many forms of chemical reactions.

Other processes. No large scale uses of solvent extraction, electrolytic separation, differential volatility, and electrodialysis are known to the writer. These techniques have found wide use as separation processes in the isolation and recovery of specific radioisotopes from fission-product mixtures and special irradiated materials, but have found little use in waste treatment and disposal.

* * *

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"Freedom to publish has always had one important qualification. One of the most important canons of science is that one must not publish without being as sure of one's results as is reasonably possible. In the entrance to the McGill Physics Laboratory, where Rutherford did some of his greatest work, there is written, 'Prove all things.' A scientist must repeat his experiments, time after time, until he is sure that he is observing a consistent behavior. Then only is he free to publish his results and to speculate about their interpretation. The greatest sin in science is to publish hastily the results of half-baked experiments; Rutherford never forgot or forgave sins of that kind."

—Sir John Cockcroft, in a lecture, Oxford, August 9, 1951

Problems in the Use of Fission Products

Wide industrial use of reactor wastes is indicated by an AEC-sponsored Stanford Research Institute study. The findings, summarized here, show that many problems remain to be solved

A SUBSTANTIAL DEMAND by industry for the huge stores of fission products that result from the production of plutonium will exist if technical and marketing problems can be worked out. This is indicated by the results of a study* recently completed by the Stanford Research Institute.

A market of the order of hundreds of thousands, or even a few million, curies per year seems likely if the price is a dollar or so per curie. If the price is $50–100 per curie, the market will probably be in the tens of thousands of curies per year.

New and improved products, reduced manufacturing costs, and lower prices for certain articles are likely. It should be possible for the separation, preparation, and distribution costs of the fission products to be paid for by their sale. A list of the suggested industrial applications is given in the table on the following page.

The greatest potential for use seems to be in the case of medium and high activity (per unit weight) gross and semi-refined fission products. No promising large-scale uses have been found for unprocessed gross fission products, such as those now stored at Hanford. If they are to be of use, these latter will have to undergo additional refinement and concentration.

Commission Problems

The Atomic Energy Commission faces both technical and marketing problems in connection with the large-scale use of fission products. These problems are many and difficult, but are regarded generally as surmountable.

Major technical problems are involved in the design of processing plants to separate the fission products; in engineering the sources of radioactivity into forms suitable for various purposes; and in supplying fundamental knowledge on which to base development of industrial applications. Marketing problems exist in such matters as pricing policy, promotional effort, engineering services, mechanics of distribution, training of personnel, patent policy, inspection and reports policy, safety regulation, and safety education. The ultimate success of the program for the industrial use of fission products depends on the solution of these interrelated problems. The nature of the solutions will depend largely on industry's needs.

The primary problem from the Commission's point of view is the processing and separation of the fission products. There is now in construction a plant designed to recover unused uranium fuel from the wastes of plutonium production. Such a plant may also be usable for the separation and processing of fission products for industry's use. It has been estimated that a facility built exclusively for fission-product processing would cost about $10,000,000.

Thus, if the processing of fission products for industrial use could be combined with the AEC's uranium-recovery program, it is conceivable that the cost to industry of the fission products would be materially reduced.

Technical Considerations

Situations in which the radiation produces a unique effect that cannot be obtained from normal industrial energy sources are the ones in which potential large-scale markets for fission products exist. If, for instance, satisfactory results can be obtained by the use of heat, the use of fission-product radiations would be uneconomical.

Specific industrial applications for fission-product radiations considered in the study may make efficient use of either beta or gamma rays, but not of both in the same application. Materials with half-lives less than 60 days seem to have little attractiveness.

Applications that require gamma rays can be satisfied by gross, semi-refined, mixed, or separated fission products with a probable minimum activity of 100 curies/lb. Applications that require beta rays can best be satisfied by separated or mixed fission products that emit betas only.

In addition to price considerations, the use of fission products will be limited by the possible greater convenience or efficiency of such other sources as other radioisotopes, X-ray machines, and cathode-ray machines. For most uses considered in the study, machine generators are not competitive with pure beta-emitting fission products. In the case of gamma emitters, it is probable that gamma radiation in sizable amounts could be obtained much more economically from fission products than could X-rays from machines.

Where machine generators can accomplish the same function as fission products, they present several advantages. A machine can be turned on or off. Thus power is used only when the radiation is needed, maintenance and repair of equipment is simplified, the personnel safety problem is lessened, and simple construction and installation procedures are possible. The ability to direct the radiation

* Industrial Utilization of Fission Products, NUCLEONICS 8, No. 5, 5 (1951).

Some Potential Large-Scale Industrial Uses for Fission Products

Application	*Market*	*Comments*
	Technology Well Developed	
Activation of phosphors	Tens of thousands of curies per year at $50 per curie.	Very pure isotopes necessary. Useful to make luminescent pigments for highway sign markers, house markers, signs in dark buildings, outdoor advertising.
Static eliminators	Thousands of curies per year at $100 per curie.	Ionization of surrounding air allows static charge to leak off. Market found in printing, textile, plastic, and rubber industries. May also prevent agglomeration of particles in fine grinding processes.
Fluorescent light tubes	Hundreds of curies per year at $100 per curie.	Permanent state of ionization of the gas will permit faster starting times and lower starting voltages.
Instruments containing radiation sources	Hundreds of curies per year at $100 per curie.	Beta-ray thickness gages. Use of one pipeline for two products by marking the interface with short-lived isotope.
	Technology Partially Developed, 2–5 years Before Ready for Use	
Industrial radiography	Hundreds of thousands of curies per year at $5–50 per curie. Small annual replenishment.	Low-energy gammas will give sharp definition. High specific activity can be had. Development of direct-reading radiographic instrument would considerably increase demand.
Cold sterilization		Good for heat-sensitive products. Gammas best because of penetration qualities.
1. Drugs and medical supplies	Millions of curies per year at $2 per curie. Small annual replenishment.	Eliminates costly aseptic techniques. Can be done after packaging. For 40-gm penicillin vial would cost $\frac{1}{5}$th of present methods.
2. Foods		Care must be taken to prevent off-taste flavors, particularly with bland foods.
a. Canned ham	Tens of millions of curies per year at $0.20 per curie. Small annual replenishment.	Long shelf-life without refrigeration. No bacterial contamination.
b. Canned peas	Hundreds of millions of curies per year at $0.01 per curie. Small annual replenishment.	Present heat methods change the taste. Demand could exceed visible supply of fission products.
	Technology Undeveloped, Basic Knowledge Available, 5 Years or More before Ready for Use	
Portable low-level power source		365 kv has been obtained by this direct conversion of nuclear to electric energy. Several hundred curies of Sr^{90} needed to get 1 watt.
Surface sterilization of fruits and vegetables		Uses betas because of short penetration. Extend shelf-life of foods with thick or tough skins.
	Basic Technical Knowledge Lacking, Speculative Uses Only	
Polymerization		Not good for present processes. Has promise for production of new polymers.
Halogenation		Gammas might supply triggering energy for light-sensitive reactions.
Oxidation		Radiation might be used to trigger very difficult oxidations.
Flame propagation		Production of ions in a combustion system might be of use in internal combustion engines and jet engines.

simplifies the engineering and operation of some potential processes. The problems of waste disposal, source preparation, and shipping of radioactive materials are eliminated.

For certain jobs, however, fission products offer important potential advantages over the use of machine-generated radiation. Fission products in sealed containers are compact sources of continuous radiant energy that could be used anywhere in a process, as long as the necessary shielding can be provided. No tube replacement is necessary, no electric power is required, nor are costly maintenance and repair operations forseen. The engineering of a continuous process that utilizes efficiently the available fission-product radiation would be relatively easy. Such processes could be used in present manufacturing methods with minor production and packaging changes.

Marketing Considerations

Radiation in large-scale use is a new problem to the technical staffs and managements of most industrial concerns. The use of radiation in industry requires reexamination of such normal business problems as safety procedures, public relations and education, public liability and insurance, government regulation, waste disposal, and the availability of personnel.

The ability of radiation to kill or damage living organisms is a characteristic that has great potential for use. This useful characteristic also makes it necessary to protect personnel from exposure to large amounts of radiation. All process-cost estimates must consider shielding requirements and instrumentation to measure radiation, and plant design must make it virtually impossible for workers to come in contact with radiation in critical amounts.

Many companies have little information on radiation safety problems, and an unfounded fear of radiation usually results from this lack of knowledge. The need is apparent for a widespread education program with a positive approach on control of the hazards of radiation. Safe use needs to be stressed, rather than danger. The potential hazards of radiation should be pointed out along with the relatively simple precautions which must be taken to avoid these hazards. Although the necessary safety procedures are unfamiliar to the majority of industrial concerns, the information on which to base safety programs is available.

The findings of the study indicate that the fission products should be used in sealed units so that dispersal of the radioactive material will be minimized. Until foolproof packaging can be devised, radioactive materials should not be incorporated in consumer products. Centralized disposal of radioactive wastes, and regular inspection of users and processors by an independent agency are also recommended.

The availability of technicians trained in the use of radioactivity is a factor in considerations of the use of fission products. Few of the companies contacted have such personnel, but the majority indicated a desire to train people in this field, even prior to the availability of the fission products.

The industrial utilization of fission products will depend, in many cases, on the applied research effort, or the rate of research investment, of individual industrial concerns. This rate of research investment will be influenced, in many instances, by the patent protection offered.

From an industrial development viewpoint, the protection of private research ideas and industrial secrets is considered of great importance. This has caused some major companies to be concerned about the AEC's requirement that results of research with radioactivity shall be reported. In this respect the experience of industries that have used radioactivity is reported to be satisfactory, but the study indicates that industry's general concern over the problem recommends the consideration of possible changes in existing law and contract provisions to guarantee the desired protection.

Results of the survey indicate that industry thinks the AEC should dispose of fission products that have served their industrial usefulness. Every industry questioned on this subject expressed the opinion that the initial price of fission products should include cost to the AEC for handling disposal when the activity declines below the point of efficient use.

The use of radioactive materials will bring industry up against a public relations problem, both internally with its employees and externally with the general public. The continuous exposure of the public to the more spectacular and destructive side of the atomic story, and the basic lack of knowledge of the nature of radioactivity, have fostered in the public mind a natural connection between destruction and radioactive material.

It appears, from the discussions, that engineering service must be an integral part of the distribution system for the fission products. Most firms contacted expressed the opinion that they will want to buy or rent prepared fission-product sources, the service required to install them, and the necessary engineering service to establish their proper operation, preferably from a single source. In the majority of cases, the radiation sources will become a part of the existing product process, and companies will want to obtain radiation processing equipment under the normal conditions of industrial sale or rental.

The suggestion that at least part of the distribution program be set up on a service rather than a sale basis has been advanced. Under this setup, an engineering service organization would design, engineer into a system, install, service, replenish, and finally take back for reprocessing or disposal, the fission-product source. This plan should be particularly attractive to small organizations who could lease a system on a package basis.

Research Programs

The AEC is undertaking, through various contractors, research and development programs concerned with the potential industrial utilization of fission products. These programs in general are devoted to basic research aspects of developing promising industrial uses for the fission products. In addition, work is under way on the processing and preparation of fission products for industrial distribution and use. The results of these programs will presumably be available to industry, to provide basic knowledge as a starting point for industrial development.

Several companies have said they are prepared to begin large-scale applied research with fission products as soon as they feel sure of a substantial supply at an economic price. Others feel that, until a market is created, they would like substantial support from the AEC in the development of industrial uses.

EDITOR'S NOTE: Copies of the report, "Industrial Uses of Radioactive Fission Products," may be obtained by writing to Project 361, Stanford Research Institute, Stanford, California. The price is $1.50.

Nomogram for Calculating Fission-Product Activities

Graphic computation makes estimation of reactor-produced fission products a short, routine job

By L. G. STANG, Jr. and PAUL D. HANCE, III*
Hot Laboratory
Brookhaven National Laboratory
Upton, New York

IT IS OFTEN DESIRABLE to know the activity of a particular fission product produced in a nuclear reactor under given conditions of flux, irradiation time, and quantity of uranium. Or, if one is interested in obtaining a given activity of a particular fission product, it is necessary to know the conditions required to produce this quantity.

These calculations are not at all difficult, but if done fairly frequently, the task can become tedious. To simplify this task we have constructed a nomogram with which these calculations can be made very easily and with great rapidity.

Before describing this nomogram and its use, we shall derive the basic equation that relates the activity of a fission product to flux, time of irradiation, fission yield, half-life of the fission product, and amount of uranium used. Only the case of a primary fission product, that is, one being formed directly by the fission of U^{235}, is considered. However, it can be shown that the same equations and thus the same nomogram apply equally well to the case of secondary and tertiary fission products (daughters and granddaughters of a primary fission product) where the half-lives of the precursors are very short compared to that of the fission product in question and where the half-life of the latter is used in the calculations.

The calculation of the activity of a secondary fission product whose half-life is not considerably greater than that of its parent is not so easily solved by the use of a nomogram and is not treated here.

Mathematical Derivation

In the following, the flux of the reactor is assumed to be constant throughout the irradiation time. If the flux fluctuates, some sort of average value would have to be used; if the reactor is shut down for an appreciable amount of time and started up again, separate calculations would have to be made for each period of operation, correcting for decay as necessary. "Burn-up" of a fission product due to neutron capture is negligible in all but a very few cases and has been ignored in these calculations.

Let N be the number of atoms of a particular fission product. The rate of increase of this isotope, dN/dt, will be equal to the difference between the rate, R, at which it is formed and the rate, λN, at which it decays, where λ is the decay constant characteristic of that radioisotope. Thus

$$dN/dt = R - \lambda N \qquad (1)$$

With R constant, Eq. 1 is a linear differential equation. Its solution can be written as

$$N = e^{-\lambda T}\left(\frac{R}{\lambda}e^{\lambda T} + C\right) \qquad (2)$$

Assuming $N = 0$ when $T = 0$, Eq. 2 becomes

$$N = \frac{R}{\lambda}(1 - e^{-\lambda T}) \qquad (3)$$

Since the activity, A, of a radioisotope is by definition equal to its rate of decay, λN

$$A = R(1 - e^{-\lambda T}) \qquad (4)$$

The rate of formation, R, is clearly the product (fy), where f is the total number of fissions occurring per unit time in the uranium in question and y is the fraction of these fissions that produces the desired product, i.e., its "fission yield." Remembering that for thermal neutrons, only the U^{235} undergoes fission, the number of fissions, f, is then equal to the product $(N_{235}T_f\phi)$ where N_{235} is the number of atoms of U^{235} present in the sample, T_f is the cross section for fission of U^{235} in cm^2, and ϕ is the flux in neu-

* Present address: University of California, Berkeley, California.

trons/cm²/sec. Clearly, N_{235} is equal to the product of the weight of uranium sample times Avogadro's number times abundance of U^{235}, divided by the atomic weight of uranium.

The units of A in Eq. 4 are disintegrations per unit time. Defining a curie as that amount of activity that decays at the rate of 3.7×10^{10} disintegrations per second, A can be converted from disintegrations per second to curies by dividing by this value. Thus, using Avogadro's number $= 6.02 \times 10^{23}$, atomic weight of uranium $= 238$, abundance of U^{235} in natural uranium $= 0.719\%$, and the cross section for U^{235} fission $= 545$ barns $(1) = 545 \times 10^{-24}$ cm² in Eq. 4 gives

$$A = (2.68 \times 10^{-15})(\text{weight of sample})(\phi y)(1 - e^{-\lambda T}) \quad (5)$$

But $\lambda = 0.693/\tau$, where τ is the half-life of the fission product. Thus

$$A = 0.00268y(1 - e^{-0.693T/\tau}) \quad (6)$$

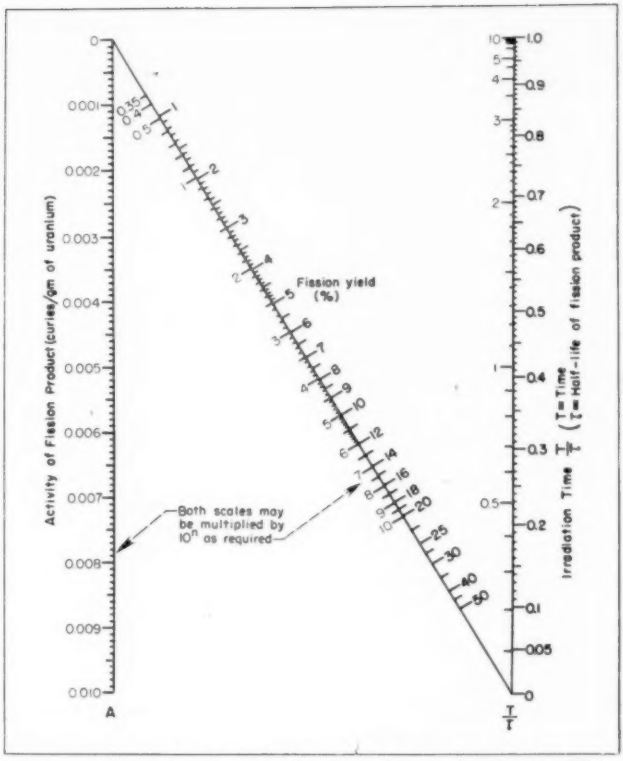
where A is the activity in curies of a fission product produced in one gram of natural uranium being irradiated for a time T in a flux $\phi = 10^{12}$ n/cm²/sec, and where y is the per cent fission yield of that product.

Note that as T/τ approaches infinity A approaches $0.00268y$, the "saturation activity" for that radioisotope.

Use of Nomogram

Equation 6 has been represented in nomogram form by setting up the proper determinants and following standard procedures (*2*). The nomogram is very simple to use. To find the activity of a fission product, lay a ruler across the nomogram intersecting the appropriate irradiation time and fission yield and read the value where the ruler intersects the activity scale. Conversely, to find what irradiation time is required to produce a given activity, lay a ruler intersecting the appropriate activity and fission yield values and read the irradiation time directly.

To facilitate use of the nomogram, two different scales have been used for the fission yield and the irradiation time. Either may be used depending on the particular irradiation time, but the right-hand scale (heavy type) of one must be used only with the right-hand scale of the other, and likewise the two left-hand scales (light type) must be used with each other.



Nomogram showing relation between irradiation time, fission yield, and activity of fission product obtained from uranium in thermal-neutron flux of 10^{12} n/cm²/sec

The absolute value of the intersection on the fission-yield scale is unimportant. For instance, if a given fission product has a fission yield of 0.04%, the ruler can be passed through the point 4 on the fission-yield scale, and the resulting activity as read on the scale is then multiplied by $\frac{1}{100}$. This is illustrated further in the following example.

Problem. A kilogram of uranium is to be irradiated at a flux of 10^{11} n/cm²/sec for a period of 77 hours. Find the activity of Te^{132}. The half-life of Te^{132} is 77 hours, making $T/\tau = 1$, and the fission yield is 3.6% (*3*).

Solution. Using the right-hand scales and laying a ruler across 1.0 on the time scale and 3.6 on the fission-yield scale, one reads 0.00485 on the activity scale. Multiplying this by 1,000 (grams of uranium used) and by $10^{11}/10^{12} = 0.1$ to correct for the flux used, gives 0.485 curies of Te^{132} to be expected.

In this problem the left-hand scales could be used; if this is done one still reads 0.00485 on the activity scale. Also, the ruler could be laid across 1 on the left time scale and, by interpolating, 0.36 on the left fission-product scale; in this case one would read 0.00049 on the activity scale. This is $\frac{1}{10}$ the correct value since the fission yield used was $\frac{1}{10}$ the proper value.

If other than natural uranium is being irradiated, the activity should be multiplied by the per cent abundance of U^{235} in the sample used and divided by 0.719.

* * *

The authors are indebted to Mr. Frank Dugan and Mr. E. Sperry who did the actual plotting of the scales.

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Electronic Apparatus for *In Vivo* Assay of Plants*

A circuit has been designed to count up to four samples with the use of only one scaler. The heart of the apparatus is a system of relay-fed rotary step switches

By R. P. MARTIN
Department of Agriculture
University of Oxford
Oxford, England

RADIOACTIVE TRACERS provide a method for studying the movement of substances into and within living organisms. The value of such procedures has been recognized since the early days of tracer investigations, and they have been used for diagnostic and other purposes in medicine (*1*). However, little systematic work appears to have been undertaken to develop counting equipment especially suited to detailed investigations of this type, although many different kinds of special counter tubes have been designed.

Thus, when we decided to study the diurnal pattern of translocation of phosphorus in living plants, it was found desirable to devise equipment whereby the impulses from a number of counters could be recorded for periods of several days. With such a device, the movement of the labeled phosphorus into different leaves of a plant could be studied.

The sensitivity of plant meristems to radiation injury (*2, 3*) makes it essential to employ low activities in work of this type. Thus it was necessary to record low counting rates, perhaps 20–50 cpm. For this reason, a scaling unit was used rather than a counting-rate meter.

Because of the cost of such equipment, the possibility was explored of using a switching mechanism whereby the impulses produced in a number of counting tubes could be recorded in sequence by a single scaling unit and recorder. Provided that the periods between successive recordings with the same counter were short compared to the time required for a significant change in counting rate to occur, this intermittent recording would be adequate. For the particular application for which the apparatus was built, a maximum of four counters appeared to be appropriate, but this number could be increased.

So that a minimum of space in the controlled-environment room in which the plants were situated would be occupied by the equipment, it was constructed in a number of units, the more bulky of which were placed in an adjoining room. The layout of the equipment is shown diagrammatically in Fig. 1; the position of the wall of the controlled-environment room is shown by the broken vertical line. A photograph of some of the equipment is shown in Fig. 2.

At any time, one counter is connected by the counter switch to its appropriate power supply and to the quench unit which in turn feeds the scaling unit. Pulses from the scaling unit operate the recorder.

The switch-control unit provides for the following variations in the mode of operation:

1. Length of time during which each counter is connected can be $\frac{1}{2}$, 1, 2 or 4 min.

2. The number of counters in use can be 1, 2, 3, or 4.

3. The scale factor can be varied in multiples of 2 from 1 to 128 for each counter independently.

No description will be given of those parts of the equipment which are of standard types, namely the power supply (type 1007) and the quench probe unit (type 1014A). The timing source is a pendulum master clock giving $\frac{1}{2}$-min impulses with a relay system to provide the 1-, 2-, and 4-min impulses.

Four commercial end-window counter tubes (type GM4) are used, mounted in simple steel holders. No attempt has been made to provide shielding against cosmic radiation, since this would add considerably to the bulk and weight of the holders. Complete shielding against β-radiation is provided by the holders, except for a small opening close to the counter-tube window. A platform is provided at the end of the holder to support the leaf of a plant against the window. Light plastic clips prevent movement of the leaf.

In the operation of the equipment, the only difficulties encountered were due to variations in the performance of

* Paper presented at the Radioisotopes Techniques Conference, Oxford, England, July 19, 1951. Proceedings of the conference, arranged by the British Atomic Energy Research Establishment, will be published by H. M. Stationery Office, London.

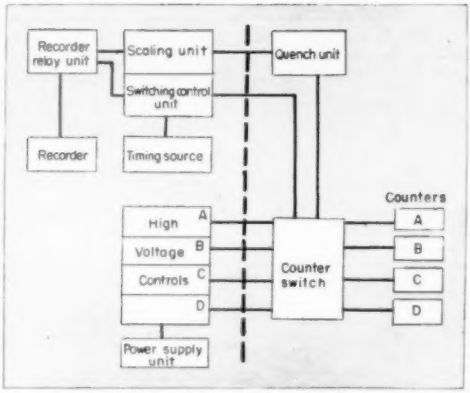

FIG. 1. Block diagram of the layout of the equipment. The dotted line shows the position of the wall between the controlled-environment room and the room containing the other equipment

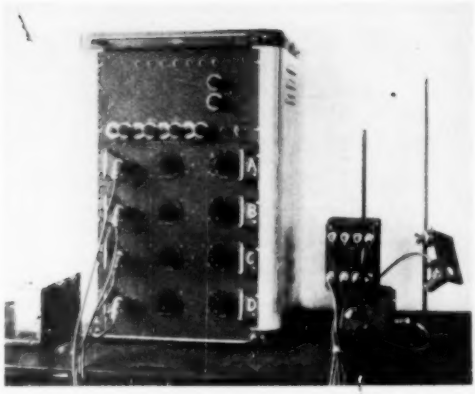

FIG. 2. From left to right, the components are: recorder, rack containing scaling unit (above) and power supply, counter switch (above) and quench probe unit, and one counter tube in holder

the counter tubes. It has been found that a number of counters have a background rate which varies with temperature, the effect developing after a short period of use. This change in counting rate has been as much as 50% over a temperature range of 2–3° C. The effect appears to be additive, thus it is of greatest consequence when counting rates are low. The elimination of this fault demands further investigation.

Counter Switch and Control

The counter switch and the switching control unit are conveniently described together since their operation is closely interlinked. The counter switch is situated between the counter tubes and the quench probe unit, while the switching control unit is built into the same chassis as the scaling unit, the controls being on the front panel. The counter switch and switching control unit are connected together by a multi-core cable.

Counter switch. The counter switch circuit is shown in Fig. 3. It consists of an electromagnetically operated rotary switch mechanism which is rotated through 360° by 104 impulses received by the driving magnet, *SC*. The mechanism carries four switches, *SC*1/1, *SC*1/2, *SC*1/3, and *SC*2. The switch *SC*2 breaks at each operation of *SC*. *SC*1/1 and *SC*1/2 are both rotary switches with sets of four contacts spaced at 90°. The former, *SC*1/1, is constructed of two fixed sheets of polythene each carrying four contacts. Between these sheets, a polythene disk rotates carrying a pair of wipers which connect opposite pairs of contacts. This type of switch has a high insulation resistance and low capacity to ground; moreover it is easily constructed. *SC*1/2 is a standard single-pole Yaxley switch. *SC*1/3 is a single-pole cam-operated switch which breaks for one step only at intervals of 90°. The mechanism is so arranged that *SC*1/1 and *SC*1/2 are closed when *SC*1/3 breaks.

One set of contacts of *SC*1/1 is connected to the four counter-tube plugs. The other set is connected to the appropriate power-supply plugs by 10-megohm load resistors, R_{27}–R_{30}, and to the quench unit lead by 0.001-μf capacitors with good insulation, C_{13}–C_{18}.

The other switches are used for controlling the operation of the mechanism. Two relays, *XS* and *XU*, are also incorporated for this purpose.

Switching-control unit. The circuit of the switching-control unit is also shown in Fig. 3. The switches it contains are a time-selector, *S*3, a counter-selector, *S*4, and four scale-factor selectors, *S*2*A*, *S*2*B*, *S*2*C*, and *S*2*D*. It also contains relays *CA*, *CB*, *CC*, *CD*, and *CE*. The signal lamps, *LP*9, *LP*10, *LP*11, and *LP*12 are mounted on the front panel of the scaling unit.

Operation. A 50-volt, d-c, supply is provided across terminals *b* and *c* (Fig. 3). Timing pulses are fed into the selector switch, *S*3, from the time source at intervals of ½, 1, 2, and 4 min. The signal lamps are operated on 230 volts, a-c (terminals *w* and *x*).

A pulse from the time source operates *CE*. Contact *CE*2 connects terminals *c* and *e*, and this operates the recorder relay unit. The effect of closing *CE*1 is determined by the setting of the counter-selector switch, *S*4. This has five positions, *A*, *AC*, *ABC*, *ABCD*, and *S*. In position *A*, only counter *A* is used; in the next three positions each of the selected counters is used in turn; the fifth position stops the operation of the switch so that whichever counter is connected remains so.

When the setting of *S*4 is *ABCD*, closing of the contact *CE*1 makes a circuit from the +50-volt, d-c, supply, *c*, through *XU*, *SC*2, and *XS* to the −50-volt terminal, *b*. *XU* operates and closes contact *XU*1 which connects the 50-volt supply across R_{24}, *SC*, and *XS*. *SC* is thus operated, the current through it being regulated by R_{24}. *SC*2 breaks and releases *XU*, which breaks *XU*1 and releases *SC*. This moves the switch mechanism and causes the cam-operated switch, *SC*1/3, to close, thus providing a circuit independent of *CE*1. Release of *SC* closes *SC*2 and again energizes *XU*. *XU* and *SC* continue to operate intermittently at a rate of about 40 steps per second. The operating current of

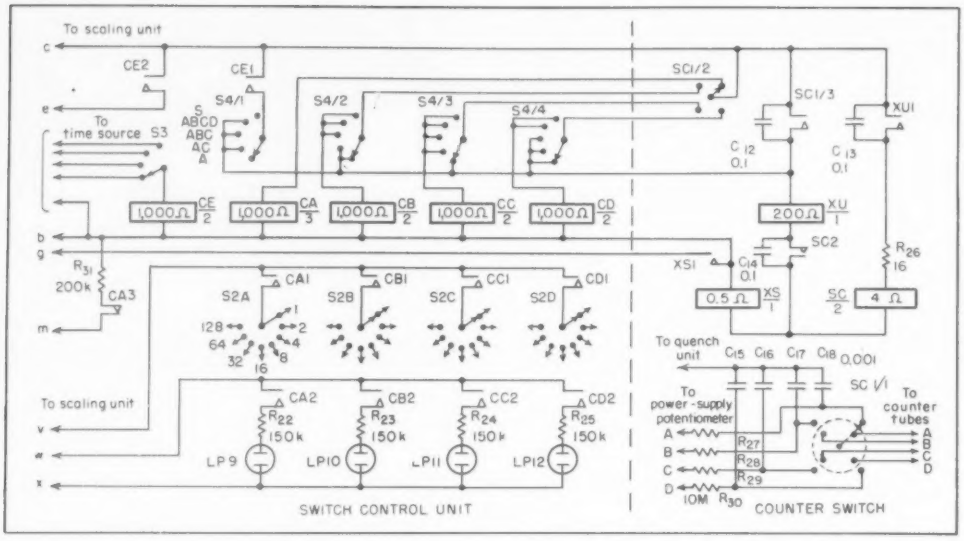

FIG. 3. Circuits of the counter switch and switching control unit. The heavy rectangles represent relay coils with their resistance given. The symbols beside the rectangles give the number of contacts and identification letters which correspond to other contacts shown

SC is sufficient to energize *XS* which makes *XS*1. This connects terminal *g* to *b*, and prevents the recorder from counting while the switch is moving.

The mechanism continues to rotate until it has moved through 90° (26 steps), at which point *SC*1/3 breaks, thus preventing further operation. Switch *SC*1/2 operates the relay (*CA*, *CB*, *CC* or *CD*) corresponding to the counter now connected, and thus the appropriate scale-selector switch and signal lamp are switched into circuit.

By altering the setting of *S*4 one or more counters can be omitted. For example, if the *ABC* position is chosen, the connections of *S*4/4 are changed so that when *SC*1/2 reaches the position corresponding to counter *D*, relay *CD* is not operated and contact *SC*1/3 is shunted by *SC*1/2. Therefore, the counter switch continues to move until counter *A* is brought into operation. Similarly, counters *B* and *D* can be omitted by setting *S*4 to position *AC*. If counter *A* alone is required, the counter switch is automatically brought to this position by an action similar to that above, but since *S*4/1 is open at this setting time pulses do not operate the counter switch. The setting *S* of the selector switch *S*4 disconnects the time pulses also, but leaves the counter switch in whichever position it is at the time.

The capacitors C_{12}, C_{13}, and C_{14} are provided to reduce sparking at the relay contacts.

Scaling Unit

The circuit of the scaling unit is shown in Fig. 4. A series of scale-of-two stages has been used since this permits maximum flexibility in choice of scale factor and also permits use of plug-in units. Moreover, decade circuits would be without any advantage in this instance.

Incoming pulses from the quench unit are fed to the control grid of V_1. The cathode of this tube is maintained at a positive potential by means of R_3 so that the tube is cut off in the absence of a pulse. The circuit is therefore insensitive to negative pulses, but positive pulses are amplified and reversed in polarity to provide large negative pulses at the anode suitable for operating the scale-of-two stages.

The connections *F*, *A*, *B*, *C*, and *D* go to the quench unit via a Plessey Mk4 plug and a multicore cable. Connection *F* is for the signal lead; the other connections provide power for the quench unit.

The reset connections on the scale-of-two stages are grounded, since it is unnecessary to reset the stages between successive counts. The error due to this is random and small compared with statistical fluctuations and with the errors of measurement of the trace on the recorder.

Neon lamps, LP_1–LP_7, are provided to give a visual indication of the operation of the scaling circuits.

The output stage is connected to the scale-of-two units through the scale-factor selector switches, *S*2*A*, *S*2*B*, *S*2*C*, and *S*2*D*, and through the relays, *CA*, *CB*, *CC*, and *CD*, of the switching-control unit (Fig. 3). This stage is a standard flip-flop circuit, in which the left-hand half of V_2 is normally conducting. A negative pulse on the control grid of this half of the tube triggers the circuit, and provides a voltage across terminals *a* and *d* which operates a relay in the recorder relay unit, for a period of about 50 msec.

The power supply provides 300 volts, d-c, for operating the scaling unit, the quench unit, and the recorder, and also a negative supply of 100 volts, d-c, for the quench unit. This is stabilized by the neon tube, V_4. The main switch connects the transformer, *T*1 to the 230-volt, a-c, supply, and also connects the 50-volt, d-c, supply for the

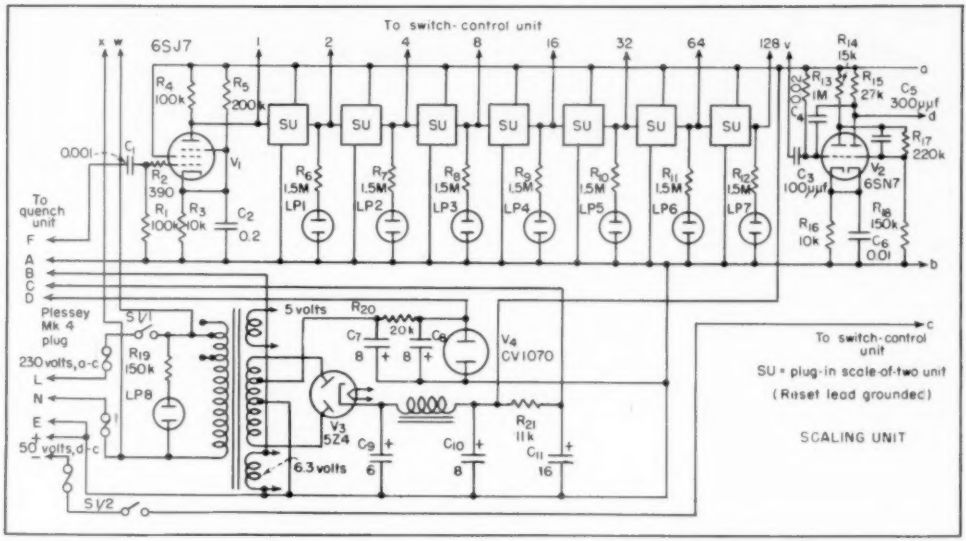

FIG. 4. Circuit diagram of the scaling unit showing scale-of-two components

relays and recorder. This is provided by means of a transformer and a selenium rectifier.

Recorder

In the initial stages of the work counts were recorded on 'Teledeltos' paper, on the surface of which black marks are made by the discharge of a capacitor between a metal stylus and a table over which the paper is passed. The mechanism is arranged so that the stylus is moved a small distance across the paper by each impulse from the scaling unit. Thus a series of tracks is obtained. A darker spot at the end of each track serves to mark those points clearly. For ease of identification the equipment is arranged so that a darker track is produced by counts from one of the counters. A typical portion of recorder paper is shown in Fig. 5. The necessary relays for controlling the operation of the recorder are contained in the recorder relay unit which is built into the scaling unit. The recorder will not be described in detail since for many applications a printing register, which records the total count for each period, offers a number of advantages, but such a register has not been available hitherto. It may be noted that the present recorder is useful in giving a visual indication of changes in counting rate.

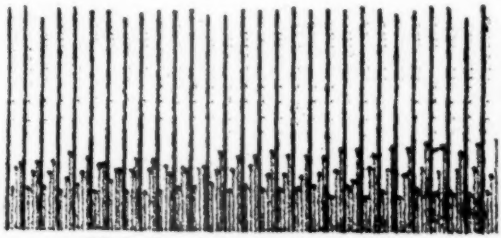

FIG. 5. Typical specimen of recording paper

Application

A typical experiment which has been carried out using this equipment is the study of diurnal changes of the labeled-phosphate content in the leaves of barley seedlings. Plants grown in water culture were used; their third leaves were expanding during the period of the experiment.

The plants were treated for 24 hr with a labeled-phosphate solution containing 0.001 parts per million of phosphorus having an activity of about 2 μc per liter. This treatment was followed by treatment in a phosphate-free medium for the remainder of the experimental period of 4 days.

Counters were attached to the first and second leaves of two plants. It was found that while the activity in the first leaf rose during, and for a short time after, treatment, little further change occurred. In the second leaf, which was still growing, the activity showed a significant diurnal rhythm; the minimal value occurred during the dark period. The physiological interpretation of this and similar experiments will be considered at another time.

* * *

Thanks are due to the Atomic Energy Research Establishment, Harwell, for the loan of the recorder and for advice; in particular, thanks are due to Mr. A. E. Bennett.

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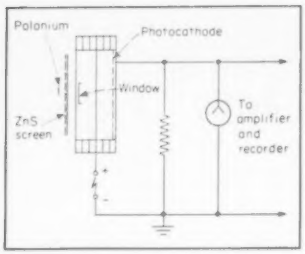

FIG. 1. Scintillation counter developed by Krebs in 1941

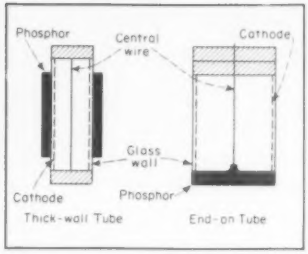

FIG. 2. Scintillation G-M tubes developed by Mandeville and Scherb in 1950

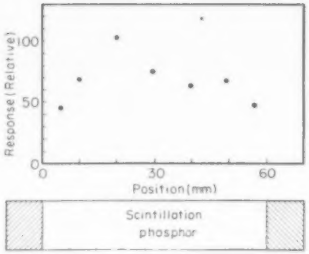

FIG. 3. Variation of response with source position along axis of thick-wall tube

Tests on Scintillation G-M Tubes

By V. M. DAGGS, W. H. PARR, and A. T. KREBS
U. S. Army Medical Research Laboratory
Fort Knox, Kentucky

THE PRINCIPLE of demonstrating and counting scintillations with a highly sensitive photoelectric device, first applied by Krebs (*1*) in 1941, has been developed and used extensively by Blau and Dreyfus (*2*), Broser and Kallman (*3*), Coltman and Marshall (*4*), Mandeville and Scherb (*5*) and others.

Present development of these tubes is characterized by the application of special photon Geiger-Müller tubes as scintillation detectors. These tubes offer certain advantages over photomultipliers. If their properties and characteristics are known and correctly applied, they can open new possibilities for radiobiological research.

Two problems are of importance at the moment. The first is the development of a tube that will be sensitive over a wide wavelength range in the visible and infrared regions. The second is the improvement of the tube's response to radiation, especially alpha radiation, as a function of the position of the radiation source. While studies of the first problem are in progress (*6*), little has been done or is known concerning the second problem. A few preliminary test measurements have been made and are reported here.

The scintillation counter built and used by Krebs in 1941, consisted of a separate scintillation screen and tube, as shown in Fig. 1. Recently developed tubes are directly coated with the scintillation substance. The tubes developed by Mandeville and Scherb (*5*) in 1950 are shown schematically in Fig. 2. These tubes are similar in design to the commercial tubes used in our tests.

Tubes Tested, Sources Used

Three different scintillation G-M tubes manufactured by Nuclear Research Corp., Philadelphia, Pa., were available for the test measurements.

1. A thick-walled alpha scintillation tube, model NRG-S 10A.
2. An end-on alpha scintillation tube with 1-in. diameter, model NRG-S 20A.
3. An end-on alpha scintillation tube with 2-in. diameter, model NRG-S 25A.

The scintillation phosphors of the tubes were covered with a thin aluminum foil of about 0.25 mg/cm² as protection against extraneous light. The tubes were operated in the Geiger plateau region, 850 to 950 volts, with a model 163 scaling unit manufactured by Nuclear Instrument and Chemical Corp., Chicago, Ill.

For comparison purposes, measurements were also made on a normal thin-end-window G-M tube, model TGC-1, serial number 7-X, manufactured by Tracerlab, Inc., Boston, Mass. The window thickness is 2.34 mg/cm².

The alpha-ray sources used in these measurements consisted of polonium precipitated on nickel strips. These sources were obtained from Canadian Radium and Uranium Corp., New York. These sources have activated areas of 2×2 and 5×5 mm, and strengths of 0.0001, 0.0004, 1.0, 3.0, and 5.0 mc.

The source used in carrying out each investigation was mounted on a mechanical microscope stage so that its position in relation to the tube could be changed and accurately measured.

Results

Two sets of response measurements were made for each scintillation tube: response as the source was moved parallel to the tube, and response as the source-to-tube distance was varied.

Thick-walled alpha scintillation tube. The response measurements for this tube are shown in Figs. 3 and 4. Figure 3 shows the results obtained with the polonium source 13 mm from the tube axis, or about 2 mm from the surface of the phosphor. No windows were used, the size of the source being the limiting factor.

The response of the tube to a source moved parallel to its axis varies with the position of the source. The response of the normal G-M tube is uniform over its length (*7*).

The scintillation tube responds to alpha radiation when the source is within the alpha-ray range. As the distance is increased, the response decreases until only the background is counted, as indicated in Fig. 4.

The influence of the size of the scintillation area was studied by using windows. With a uniform distribu-

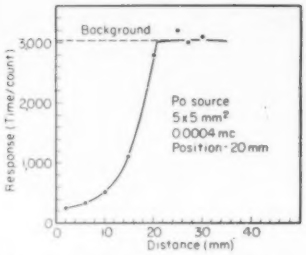

FIG. 4. Variation of response with changing source-tube distance for thick-wall tube

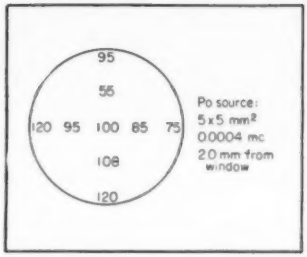

FIG. 5. Response over window of 2-in. end-on tube

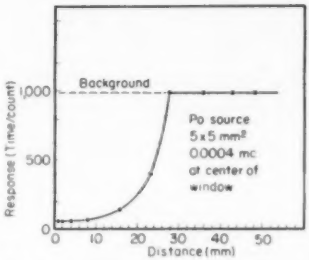

FIG. 6. Variation of response with changing source-tube distance for end-on tube

Preliminary measurements show that the response of commercial scintillation G-M tubes varies with the position of the source of radiation. These tubes should be of use in range dependence and radiobiology studies

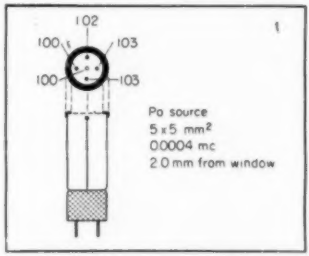

FIG. 7. Response over window of normal G-M tube

tion of polonium on the carrier metal, the counting rate obtained was found to be directly proportional to the phosphor area exposed. The smallest area studied was 0.45 mm². With this area, an increase in counts significantly different from the background was obtained in normal counting times.

End-on scintillation tubes. Results obtained with the 2-in. tube are given in Figs. 5 and 6. Similar results were obtained with the 1-in. tube.

The response over the window varies to a high degree with the position of the source. The differences can be 100% and more, showing that more work is necessary to obtain a uniformly responding scintillation phosphor.

The tube shows a high area of sensitivity. With the weakest alpha preparation, a phosphor area of 0.45 mm² gave a count much higher than background in normal counting times.

Normal end-window tube. For comparison, Fig. 7 shows the response obtained with a thin-window G-M tube.

Comparison. The response of a G-M tube in general depends on construction of the tube and the geometry in which it is used (*7, 8, 9*). The normal G-M tube is so highly perfected that the response of the tube to alpha radiation is practically constant over the whole counting area of the window. This is especially true when the edges of the tube window are protected by an overlapping ring, as in the case of the generally used bell-jar type of tube.

The test measurements on three different scintillation G-M tubes show that this is not yet the case for these tubes. The response of each of the three tubes depends greatly on the position of the radiation source in relation to the tube's geometry and construction. This fact is of decisive importance in quantitative work and has to be considered in comparative studies, where reproducibility is to be expected.

The distance measurements are in good agreement with the characteristic properties of alpha particles if one considers the absorption in the aluminum foil and in the phosphor. Beyond the range of the alpha particles (3.84 cm in air for polonium alphas) there should be only the background of the tube. All the measurements demonstrate this property of alpha particles and show the usefulness of the tubes for range-dependence studies.

The most important consideration for radiobiological work is the fact that the sensitive scintillation area can be very small. In these studies, an area of 0.45 mm² was large enough to give reliable counts with a relatively weak alpha source in short counting times. No difficulties can be expected in measuring smaller activities under general G-M counting conditions.

This characteristic of the scintillation G-M counter is necessary for its use in special radiobiological work such as measuring activities in body cavities and in small tissue volumes. For this work, a smaller version of these tubes similar to the miniature counter developed by Curtis (*10*) might be developed, or light-conducting rods of Lucite or quartz might be used with a high-area-sensitive G-M photon tube.

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A Salute to the 1951 Nobel Scientists

GLENN T. SEABORG and EDWIN M. McMILLAN, winners of the chemistry prize "for their discoveries in the chemistry of the transuranium elements."

JOHN D. COCKCROFT and E. T. S. WALTON, winners of the physics prize "for their pioneer work on the transmutation of atomic nuclei by artificially accelerated atomic particles."

Their names are added to the list of other

Nobel Laureates

THE SCIENCE of the atomic nucleus is not yet an "open book." To the scientists who have helped crack the binding and turn its many pages, however, the news from Stockholm last month was most welcome. It brought word that, once again, their co-workers had been rewarded with one of the highest civic honors, a Nobel prize. Four nuclear scientists were to share the 1951 Nobel Awards in Physics and Chemistry.

NUCLEONICS joins the world in saluting the recipients: Sir John D. Cockcroft, director of the Atomic Energy Research Establishment at Harwell, England; Dr. E. T. S. Walton, fellow of Trinity College, Dublin, and professor of natural and experimental philosophy; and Drs. Glenn T. Seaborg and Edwin M. McMillan, of the Radiation Laboratory and the Departments of Chemistry and Physics, respectively, of the University of California.

The pioneer work that brought Cockcroft and Walton the physics award in 1951 was performed in 1932. They constructed the first man-made particle accelerator. This machine, a high-tension apparatus that produced 700,000 volts, was the forerunner of such powerful accelerators as made possible the discoveries for which Seaborg and McMillan were honored.

With this apparatus, as Lord Rutherford explained simply to an afternoon meeting of the Royal Society in 1932, two of his workers in the Cavendish Laboratory "successfully disintegrated the nuclei of lithium and other light elements by protons entirely artificially generated by high electric potentials." Cockcroft and Walton, the two workers, had thus accomplished the first artificial transmutation of chemical elements.

It is interesting to note that the work behind the 1951 prizes in both physics and chemistry was based on artificial transmutation. Cockcroft and Walton dealt with low-speed particles and light elements; Seaborg and McMillan with high-speed particles and heavy elements.

Six elements were added to the periodic table as a result of Seaborg and McMillan's work. Known as the transuranium elements, they are *neptunium*, *plutonium*, *americium*, *curium*, *berkelium*, and *californium*.

NOVEMBER 10, 1939.
NOVEMBER 10, 1944.
NOVEMBER 16, 1945.
NOVEMBER 11, 1950.
WIN NOBEL PRIZES
Pauli of Princeton Institute and Hahn, Who Is Believed to Be Here, Are Honored
Prof. Wolfgang Pauli
Physics
Dr. Isidor I. Rabi
2 U. S. SCIENTISTS WIN NOBEL PRIZES
Dr. Rabi and Dr. Stern Receive 1943 and 1944 Awards for Research in Physics
Nobel Prize to U. S. Chemi
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AWARD GOES O. LAWRENCE
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EVOTE IT TO WORK
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NOBEL PRIZE WINNER
NOBEL PRIZE WINNERS
NOVEMBER 5, 1948.
NOVEMBER 4, 1949.
Patrick M. S. Blackett

Announcements of 1938-1950 Nobel awards in nuclear science

From *The New York Times*

# of Nuclear Science

With co-workers, McMillan is generally credited with the discovery of neptunium, with early work on plutonium, and with modifications in the Berkeley cyclotron of Ernest O. Lawrence that resulted in the production of particles of higher speed than were available for this work before 1940. Seaborg hypothesized the existence of the transuranium elements and with co-workers, synthesized measurable amounts of plutonium, americium, curium, berkelium, and californium. These six elements were created in submicroscopic amounts by the transmutation of uranium, and their physical and chemical properties identified after a tedious process of purification.

This complex task, carried out between 1940 and 1950, brought Seaborg and McMillan the 1951 Nobel award in chemistry. Perhaps it would have been more fitting to call it, for 1951, the "award in ultra-microchemistry"—for their task also included devising ingenious means for handling the less-than-a-millionth-of-an-ounce amounts of the elements involved.

Nobel Prizes in Nucleonics

The four 1951 awards reflect the tremendous strides made in the field of atomic energy in the past half century. Twelve of the twenty-two Nobel prizes in physics and chemistry awarded since 1938 have gone to nuclear scientists. Shared prizes bring the total number of these scientists to fourteen.

Nucleonics is considered to have come into its own as a science at about the time (1938–1939) the chemical and physical laboratories of the world started to produce evidence that neutron bombardment could bring about rearrangement in the structure of the atomic nucleus. With this period as the starting point, we would like to review the work of the Nobel laureates in nuclear science. We do so not without a passing tribute to the Nobel medalists whose previous researches in radioactivity and theories of atomic structure provided the stepping stones to the science as we know it today.

Roentgen, of course, heads the latter group. In 1901, he was given the first Nobel award in physics "in recognition of the extraordinary services he has rendered by the discovery of the remarkable rays which have sub-

sequently been called after him." Others in the group include:

- Becquerel, and Marie and Pierre Curie (1903)
- Rutherford (1908)
- Einstein (1921)
- Soddy (1921)
- Compton and Wilson (1927)
- de Broglie (1929)
- Schroedinger and Dirac (1933)
- Urey (1934)
- Chadwick (1935)
- Frederic and Irene Joliot-Curie (1935)
- Hess and Anderson (1936)

To bring the Cockcroft-Walton and Seaborg-McMillan awards into perspective, it may be of interest to examine briefly the work of their Nobel predecessors.

The Physics Awards

ENRICO FERMI. In France, the Joliot-Curies created artificial radioactivity in light elements with a relatively low positive charge by bombarding them with high-speed alpha particles, but their method worked only for light elements. Fermi, in Italy, a short time later, used a similar technique with high-speed neutrons. It worked not only for light elements but for heavier elements as well. He further found that, by first slowing down the neutrons, their power to cause a reaction was increased. Thus he was honored in 1938 by a Nobel award "for his disclosure of new radioactive elements produced by neutron irradiation, and for his related discovery of nuclear reactions brought about by slow neutrons."

ERNEST O. LAWRENCE. The Cockcroft-Walton method described earlier for accelerating protons was limited to low velocities. When the voltage was raised, insurmountable technical difficulties presented themselves. At the University of California in Berkeley, Lawrence was working out a method for accelerating particles by making them describe a helical path between the poles of an electromagnet where they are speeded up by means of an alternating electric field. "For the invention of the cyclotron, its development and the results obtained with it, especially relating to artificial radioactive elements," Lawrence received a Nobel prize in 1939.

OTTO STERN. Dirac's equation for the electron provided an expression for the spin of electrons and their magnetic moment. In expansion of Dirac's work, Stern was able to show the existence of the magnetic moment of protons and devise an accurate method for measuring the magnitude of deflection of each particle as it responded to the pull of a magnetic field. The 1943 prize went to Stern "for his contribution to the development of the molecular jet method and the discovery of the magnetic moment of the proton."

ISIDOR I. RABI. It is interesting that the work of Rabi, which was a modification of Stern's measurement technique, brought him the physics award in 1944, the year following the award to Stern. Rabi's method of measuring the magnetic behavior of atomic nuclei was based on the phenomenon of resonance and offered more precision than Stern's. The Nobel citation to Rabi paid honor to "the resonance method employed by him for the registration of magnetic properties of atomic nuclei."

WOLFGANG PAULI. The de Broglie quantum theory assumed fixed paths for electrons in the atom. Pauli postulated, in supplement to this assumption, that only two electrons could be present in every type of orbit determined by a definite combination of quantum numbers. He stated further that these electrons must have opposite spins. This principle has not only withstood all later revisions of the quantum theory but is still employed in interpreting the properties of atomic nuclei, the electric conductivity of metals, and the properties of magnetic substances. In 1945, Pauli received the prize "for the discovery of the exclusion principle, also called the Pauli principle."

PATRICK M. S. BLACKETT. An early user of the cloud chamber invented by 1927 Nobel medalist Wilson, Blackett in 1925 demonstrated that the atomic nucleus ejects a proton upon alpha-particle bombardment. Extending this use of the cloud chamber to cosmic-ray studies, he devised, in cooperation with Occhialini, a simple means of photographing the rays by exposing plates only at the time the ray passes through the chamber. His further researches contributed to our understanding of the phenomenon of pair production and annihilation radiation. The prize to Blackett, awarded in 1948, cited "his development of the Wilson cloud chamber method, and his discoveries therewith in nuclear physics and concerning cosmic radiation."

HIDEKI YUKAWA. The mathematical postulation of the presence of a field of force within the nucleus and an associated elementary particle with a mass of about 200 times that of the electron was put forth by Yukawa in 1935. Among others, Powell, in 1946 offered evidence of the existence of this particle, the meson, with his nuclear-track records as described below. In 1949, fourteen years after presentation of his theory, Yukawa received the prize "for his prediction of the existence of mesons on the basis of theoretical work on the nuclear forces."

CECIL FRANK POWELL. With his collaborators, Occhialini and Chilton, Powell confirmed not only Yukawa's theory of the meson but further showed that two different types of meson exist, the π-meson and the μ-meson. Development of special nuclear emulsions and plates that offered registration of these particles to a new degree of perfection advanced cosmic-ray research all over the world. Powell, in 1950, received the prize for his "photographic methods of studying nuclear processes and his discoveries concerning the mesons, elementary cosmic-ray particles."

The Chemistry Awards

GEORGE DE HEVESY. Before Lawrence's cyclotron offered the possibility of artificially produced radioisotopes, brilliant researches had been conducted by de Hevesy with naturally radioactive isotopes. His isotopic tracer technique to study plant and animal metabolism was a classic contribution to biochemical research and has been extended to all other fields of chemical and industrial research. The 1943 prize went to de Hevesy "for his work on the use of isotopes as tracer elements in researches on chemical processes."

OTTO HAHN. Fermi's neutron irradiation technique, for which he received the physics prize in 1938, was used to advantage by Hahn and his co-workers, Meitner and Strassmann, to study the effect of neutrons on uranium. In 1939, Hahn hypothesized that, upon neutron bombardment, the nuclei of the heaviest elements were split into two more-or-less-equal parts and that elements somewhere near the middle of the periodic table were produced by this fission. "For his discovery of the fission of heavy nuclei," Hahn was named for the 1944 Nobel award.

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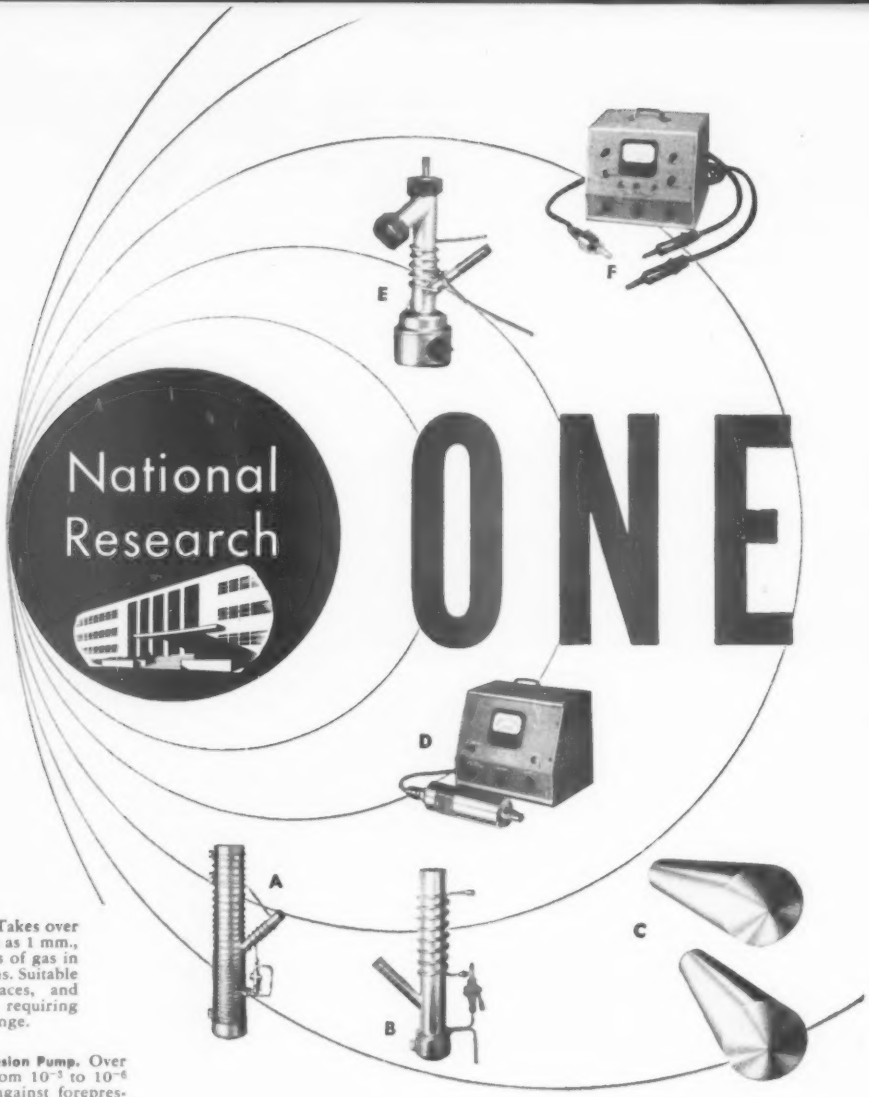

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Target Assembly for Cyclotron Irradiation of Liquids

BY WILLIAM R. McDONELL* and A. S. NEWTON
University of California Radiation Laboratory
Berkeley, California

To study the chemical products formed during irradiation of aliphatic alcohols with high-energy nuclear particles in the 60-in. cyclotron, a liquid target assembly was designed and built. The apparatus consisted of two chambers, one situated within the other. The inner chamber contained the liquid being bombarded and the liquid products formed, and the outer chamber collected the gaseous products. During the irradiation, the inner chamber was open to the outer by means of a duct to allow the gaseous products formed to escape.

The apparatus is diagrammed in Fig. 1. A photograph of the apparatus with the first inner-chamber design is shown in Fig. 2. The design follows that of R. E. Honig [*Rev. Sci. Instr.* **18**, 389 (1947)].

The target assembly was joined to the window of the cyclotron with a standard window assembly which provided an essentially rectangular window 2.5 × 7 cm into the outer chamber of the target assembly. This window was covered by two aluminum foils spaced 3.0 cm apart and cooled during bombardment by a stream of air passing between them.

The outer chamber of the assembly was a rectangular box of inside dimensions approximately 12 × 13 × 5 cm, constructed of 0.25-in. copper plate with the edges silver soldered together, and bolted against a neoprene gasket to the window assembly. It was provided with a thermocouple well with a copper-constantan thermocouple installed, and a Bourdon-type pressure-vacuum gage. A needle-valve outlet permitted evacuation and removal of gaseous products.

One wall of the outer chamber, being removable, was held vacuum tight in place against a neoprene gasket by a set of quick-opening clamps. This wall was made of Teflon to insulate it from the inner target which it supported within the outer chamber.

The first chamber used consisted of a rectangular copper box, 8 × 5 × 1.5 cm inside dimensions, one face of which was a 0.002-in. copper foil to allow passage of the irradiating beam into the liquid contained inside. In the top, an opening was provided for filling the chamber; this opening also allowed the gaseous products to escape into the outer chamber. The opening

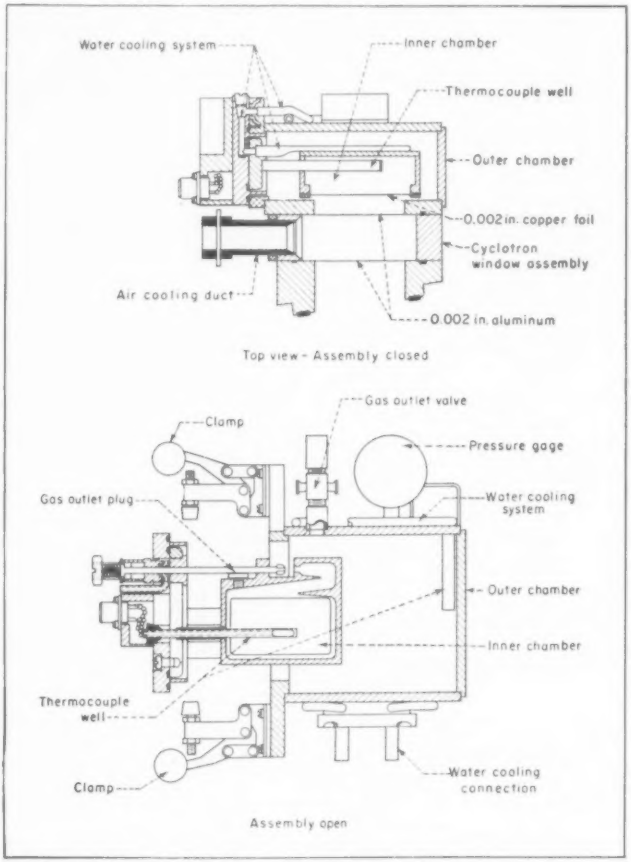

FIG. 1. Liquid target assembly with improved inner chamber

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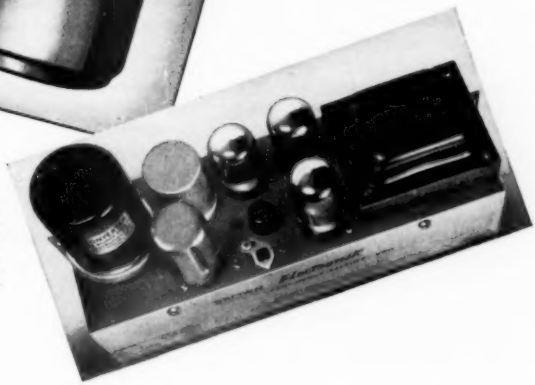

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could be stoppered closed from outside the assembly by a plug on a shaft through a Wilson seal to prevent spilling of the liquid in transporting the apparatus. The inner chamber was also provided with a thermocouple well and a copper-constantan thermocouple for temperature measurement during bombardment.

This first inner chamber was found deficient in several respects. It was located approximately centrally within the outer chamber, leaving a considerable gas volume of the outer chamber exposed to the irradiating beam. The opening at the top intended for escape of gaseous products allowed a considerable loss of liquid into the outer chamber, presumably by foaming up and out during the copious gas evolution of the bombardment.

This chamber was therefore replaced in later experiments by one of improved design. Enlarged to $8.5 \times 5 \times 3$ cm inside dimensions, it was suspended as close as possible from the window foil of the outer chamber to minimize the gaseous volume exposed to the irradiating beam. The opening at the top for filling and removing the liquids was sealed by a gasketed plug, and a separate duct, baffled in such a manner as to minimize the mechanical loss of liquid from the chamber by foaming, provided for gas escape. This duct could also be externally closed for transportation. Aside from these features this inner chamber was essentially unchanged.

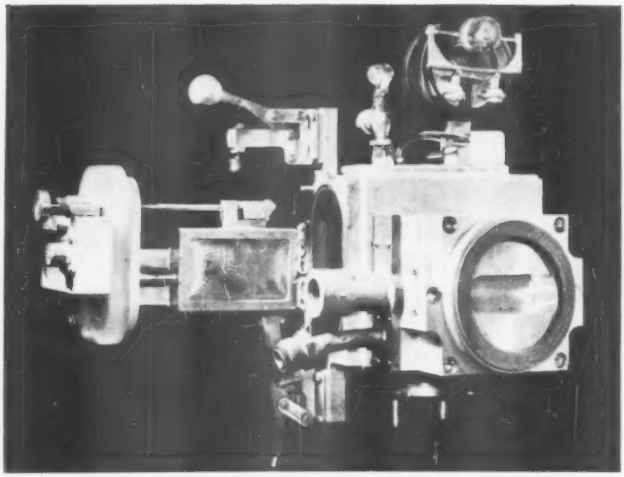

FIG. 2. Liquid target assembly with first design of inner chamber

Both inner and outer chambers were water cooled. Both were completely electroplated with gold, as was the copper-foil window of the inner chamber, to eliminate direct chemical or catalytic action with any reactant species formed during irradiation. The inner wall of the second aluminum window foil which comprised a part of the wall of the outer chamber was gold plated by molecular evaporation from a hot filament at a low pressure.

Since it became radioactive during bombardment, the assembly was provided with a lead box for shielding the experimenter during transportation and removal of the products.

Argon-Tetramethyl Lead-Methane Proportional and Geiger Counters

By PAUL E. DAMON and ROBERT F. OVERMAN

Department of Chemistry and Institute of Science and Technology
University of Arkansas, Fayetteville, Arkansas

During the course of research on the measurement of the Pb^{210} beta-ray spectrum by proportional-counter spectrometry, the Pb^{210} was introduced into the counter as gaseous $Pb^{210}(CH_3)_4$. It was observed that for certain gas mixtures of tetramethyl lead, methane, and argon, the threshold for Geiger action was exceptionally low, whereas for other mixtures the threshold was high, and the tube seemed to act quite well as a proportional tube.

Brass tubes were used during the experiment. The cathode diameters were 3.8 cm. The cathodes were thoroughly polished, cleaned, and outgassed by pumping, but were not baked or treated in any other way. The anode was of 4-mil tungsten wire. The length of the active volume was about 31 cm. The threshold for Geiger action of one of these tubes filled with 2.7 cm of argon was 1,560 volts. When 2 mm of untagged $Pb(CH_3)_4$ was introduced into the tube, followed by 6.8 cm of argon, the threshold was instantaneously high, then lowered rapidly during a period of about one minute to a low value of 560 volts, after which it rose rapidly to a high equilibrium value. A similar effect was noticed for other combinations of argon and tetramethyl lead.

A tube containing a mixture of 63.7 cm of argon and 9 mm of $Pb(CH_3)_4$ showed a threshold increasing from 900 volts two minutes after filling to 1,570 volts one hour after filling. When up to 10% methane was introduced, the threshold was stabilized at a low value, e.g., the threshold of a counter filled with 66 cm of argon, 6 cm of CH_4, and about 1 mm of $Pb(CH_3)_4$ was stable at 900 volts. The plateau was 20% per 100 volts without external quenching. When greater amounts of methane were added, the threshold rose rapidly to a

high equilibrium value. One such tube filled to 72 cm pressure (28% CH_4 and 0.02% $Pb(CH_3)_4$) was found to operate satisfactorily as a proportional tube. The gas multiplication at 1,960 volts was about 400. The counter has been in use for about two months and has shown no appreciable change in its characteristics.

The usual explanation of such low-threshold effects (*1*, *2*) is the quenching of the 11.5-ev metastable state of argon. That such an explanation is probably valid here is evident from the value for the ionization potential of $Pb(CH_3)_4$ given provisionally by Fraser and Jewett (*3*) as 11.5 ev. The stabilization reaction which takes place without methane or with methane in excess of 10% is, however, complex and cannot be explained satisfactorily by the authors.

The gas mixture with less than 10% methane shows promise as a filling for low-voltage, high-pressure cosmic-ray counters with large dimensions.

This work was supported in part by the United States Atomic Energy Commission.

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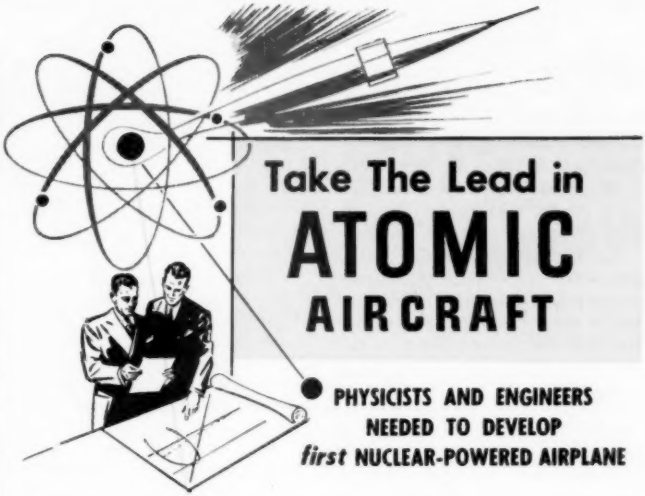

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BOOKS

Radioisotopes—Industrial Applications, by G. H. Guest. Sir Isaac Pitman & Sons (Canada), Ltd., Toronto, 1941. xv + 185 pages. $4.50.

The stated purpose of this book is stimulation of further interest in uses of pile-produced isotopes in industry, and it appears to this reviewer that the book offers a contribution in this direction, although by its optimistic presentation, it may overstimulate the uninitiated reader to the future possibilities of radioisotopes. Understandable to laymen, yet useful for technical people as a check list of ideas and source material, the discussion of most of the uses of radioisotopes is limited to general features of the work without much detail of the techniques used.

Several early chapters describe briefly the production of radioisotopes and review some fundamentals of atomic theory from the chemical viewpoint and, to a lesser extent, from the standpoint of radioactivity.

Subsequent chapters survey actual industrial applications of radioisotopes and suggestions for new uses. These are classified more or less by industry and are discussed under the following headings: metallurgical research; iron and steel production; friction and lubrication studies; applied metallurgy; glass and ceramic research; petroleum, rubber, and chemical industries; industrial hygiene and public health; miscellaneous tracer applications; industrial radiography; and radiation sources for various other applications (such as thickness gages and static eliminators).

The two final chapters cover general recommendations for radioactive-laboratory design and some health precautions in the industrial uses of radioisotopes. Six appendixes contain a good selection of reference books and bulletins and a list of useful radioisotopes, with their type and energy of radiation.

Examples of industrial uses of radioactivity have been well chosen and, in general, present the highlights of the subject clearly but quite briefly. Plentiful diagrams and photographs are, for the most part, taken from the original publications. (References to these publications at the end of each chapter are not complete in all cases.)

As the book is devoted largely to a survey of representative work by others in the field of radioactivity, it lacks a certain unity of organization which detracts to some extent from its over-all effectiveness.

The author has also retained much of the optimism for new uses proposed by the original authors. A member of the Industrial Health Division of the Department of National Health and Welfare of Canada, Dr. Guest has not attempted to annotate or give his own views on the practicality of some of the proposed ideas, except briefly in the introductory sections and in the chapter on precautions. The optimistic viewpoint does not seem to be adequately balanced by a sufficient discussion of the limitations of the radioactive technique which are known to include sometimes the undesirably large amount of activity required for many applications or the frequent impossibility of incorporating an isotope in a true tracer identical in chemical and physical form with the material being studied.

The early chapters on atomic theory, radioactivity and descriptions of instruments (limited mainly to Geiger-Müller counters) are helpful as refresher reading or as an introduction to more detailed books on the use of radioactivity, such as those listed by the author or others published more recently. As a text or reference book, this volume would lack rigorous scientific accuracy and completeness of coverage, but as a general introductory picture of the radioactive technique applied to industry, it serves a useful purpose.

—S. E. Eaton
Arthur D. Little, Inc.
Cambridge, Mass.

Radiologic Physics (2d edition), by Charles Weyl and S. Reid Warren, Jr., Charles C Thomas, Publisher, Springfield, Ill., 1951. xix + 491 pages. $10.50.

Radiological physics, as the term is commonly used, is one of those interesting borderline fields of science that really calls for some understanding, of not only physics, but also some engineering, chemistry, biology, and clinical radiology. In no one book can all of these be covered adequately, and the authors of "Radiologic Physics" have wisely not attempted to do so.

On the other hand, they have presented much material of an engineering nature that the average radiological physicist needs to know and much of a physical nature that the engineer needs to know, with the two combining as a useful source book for the clinical radiologist. Where the size of the volume does not permit lengthy specialized presentations, the reader is given adequate references.

The first eight chapters (200 pages) deal with primarily engineering subjects and a review of the elementary physics needed by the radiologist. D-c and a-c electrical circuitry is first developed and then followed by a discussion of electrical measurements and measuring instruments. There is also an extensive discussion of power problems involving high-voltage transformers and rectifiers essential for the production of X-rays over wide energy ranges.

The original chapter on electronics, as it appeared in the first edition of this book published in 1941, has been subdivided and considerably enlarged, particularly the parts dealing with electronic devices. With the rapid growth in the application of electronics in the radiological field, this is a most welcome addition. The new chapter covers the fundamentals of many new electronic control and measuring devices and should serve as a guide to when to turn to electronics for the solution of some special problem. There is also a brief discussion of the various particle accelerators such as the belt generator, betatron, cyclotron, and high-frequency linear accelerator.

The next five chapters (160 pages) deal primarily with the physics needs in radiology. This is introduced by a survey of radiation physics leading up to the modern background and serving as a basis for the more detailed discussion of X-rays and the phenomena of X-ray spectra absorption, scattering, etc. A chapter on radioactivity and nuclear physics now includes material on artificial radioactivity. It might have been hoped that the latter could have been treated at greater length but the reader is given numerous references. Next is a chapter on radiation measurements, units and devices, and

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radiation dosage for all types of radiation and particles.

The final two chapters (60 pages) deal with radiological diagnostic problems and procedures. The excellent quality of these chapters probably reflects the extensive experience of the authors in this field. There is much here which should be of value to the inquisitive roentgen diagnostician.

The book is concluded with some 50 pages of mathematics review and mathematical tables. Throughout the book are numerous sample calculations that serve as a guide in the application of the information presented.

The principal adverse comment has to do with the treatment of the various units involved in radiological physics. In the first place, while recognizing the increasing use of the mks-system by engineers, it is still pretty well avoided in most modern physics except in such specialties as microwave physics, etc. For the radiologist who learned in premedical school that physics was an evil to be passed over as painlessly as possible, the cgs-system mysteries have just begun to unfold. The introduction of another system, however correct it be, won't help him.

In the discussion of radiological units, nearly every unit mentioned in the past decade has been discussed. Some of these have been merely proposals, others used and then discarded, and still others positively discouraged. The discussion of these has not been sufficiently critical so that the inexperienced reader will know which to use or avoid. For example, on page 313, reference is made to the British "*J* unit" proposal. Actually, the British never proposed a unit called the *J* unit but used the symbol *J* in a printed report prepared primarily as a basis for discussion by the International Commission on Radiological Units. This might serve to mislead the unwary reader, particularly since the 1950 recommendations of the International Commission on Radiological Units have not been presented or discussed in detail by the authors.

—LAURISTON S. TAYLOR, *Chief*
Atomic and Radiation Physics Division
National Bureau of Standards
Washington, D. C.

Atomic Physics, by Wolfgang Finkelnburg. McGraw-Hill Book Co., Inc., New York, 1950. x + 498 pages, $6.50.

Written for seniors and graduate students in physics and chemistry, this book deals with the entire knowledge of the structure of matter, from the elementary particles up to the solid state. Mathematics is not stressed, but rather the meaning of experimental results and theories is considered in detail. The chapter headings are more or less standard for books of this sort. Following an introduction is a general discussion of the properties of the fundamental particles. Then come two chapters on atomic spectra and structure, and the quantum mechanics of atomic theory. The last three chapters cover nuclear physics, molecular physics, and atomic physics of the liquid and solid state.

BOOKS RECEIVED

Radiations from Radioactive Substances, by Sir Ernest Rutherford, James Chadwick, and C. D. Ellis. Cambridge University Press, New York, (reissue) 1951. xi + 588 pages, $11.

This is a classic work in the literature and history of radioactivity. First printed in 1930, it has just been reissued with corrections.

Philosophical Problems of Mathematics, by Bruno, Baron v. Freytag gen. Loringhoff. Philosophical Library, New York, 1951. 88 pages, $2.75.

Translated and expanded from two lectures given by the author, a lecturer on philosophy at the University of Tubingen, this volume searches into the human meaning of mathematics.

British Scientists, by E. J. Holmyard. The Philosophical Library, New York, 1951. viii + 88 pages, $2.75.

A collection of brief sketches of a score or so of British scientists who lived since the 13th century, including a short history of the contributors to atomic theory. It is illustrated with 24 handsome portraits.

OTHER LITERATURE

Atomic Energy Commission Document Price List No. 19 (issued October, 1951). A revised and cumulated listing of all AEC publications still in print which have been included in previous price lists and are available for purchase from OTS. *Copy of price list free on request from Office of Technical Services, Dept. of Commerce, Washington 25, D. C.*

Recommendations for Waste Disposal of Phosphorus-32 and Iodine-131 for Medical Users (National Bureau of Standards Handbook 49). This pamphlet was prepared by the Subcommittee on Waste Disposal and Decontamination of the National Committee on Radiation Protection (November, 1951). *GPO, Washington, D. C., $0.10.*

Background Information on Cobalt-60 Teletherapy Units (NRC Report 2496), by A. Morrison. A simple presentation of 13 pages, including glossary, explaining what the units are, how they compare with radium machines, and plans for their use. *Technical Information Service, National Research Council, Sussex St., Ottawa, Canada, $0.15.*

Absorption Corrections Used in Radium Standardization (NRC Report 2342), by J. Kastner. A comprehensive 17-page report on the method used at the National Research Council's Radiology Laboratory to estimate the true radium content of an unknown sample. *Technical Information Service, National Research Council, Sussex St., Ottawa, Canada, $0.15.*

1951 Annual Report of the Armour Research Foundation of Illinois Institute of Technology. All phases of the work of the Foundation are described in the report which commemorates "15 years of industrial research." Included are brief notes on the Foundation's bent nozzle isotope separator, radiography laboratory, betatron research, and radiac detector. *Technology Center, 35 W. 33d St., Chicago 16, Ill.*

Environment and Health. A 152-page album style book published by the U. S. Public Health Service of interest to all public and semi-public organizations and professional audiences concerned with community health problems. Nine pages are devoted to the subject of radiological health, and fifteen to industrial health. *GPO, Washington 25, D. C., $0.75.*

Compendium of Meteorology, edited by Thomas F. Malone. The entire field of theoretical and applied meteorology is brought into view in 108 articles that comprise this 1,315-page volume. *American Meteorological Society, 3 Joy Street, Boston 8, Mass., $12.*

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NUCLEONIC EVENTS

Sumner T. Pike, Last of Original AEC, Resigns; Calls for Industry to Take the Initiative Now

In an exclusive interview on the eve of his resignation from the Atomic Energy Commission last month, Sumner T. Pike said that "the time is now ripe" for industry to take note of the developments in the atomic-energy field and predicted that "big advances" will show up in the next two or three years which he cautioned industry to watch. Tendered in the fall of last year, Mr. Pike's resignation from the Commission became effective only in December. In accepting his resignation, President Truman praised Mr. Pike for "more than five years of selfless and devoted service . . . contributed to the national atomic energy program . . . during its crucial, formative years."

Asked to comment on the developments industry should pursue in the atomic energy field, Mr. Pike told NUCLEONICS that "industry will have to answer this question for itself." He added that "it will not pay to think it will take another generation before industry can get into the field" in a practical way. "Those who do think this," he said, "will be left behind."

If industry feels that security restrictions are hampering its development in the atomic-energy business, Mr. Pike pointed out, it "should take the matter up with Congress, because industry will have to take the initiative rather than the AEC." "The study of power reactors now under way," he said, "will have an important bearing on industrial activity in this field."

Mr. Pike, whose mining experience and background in business management made him a valued member of the Commission, was appointed to the five-man AEC when it was first organized to take over the atomic energy program from the military in November, 1946. The last to resign of the original AEC membership, which included David E. Lilienthal, Robert F. Bacher, Lewis L. Strauss, and W. W. Waymack, Mr. Pike plans to retire and made his resignation effective December 15.

In 1950, when he was proposed for a new four-year term on the Commission, the Joint Congressional Committee on Atomic Energy, by a 5 to 4 vote, attempted to block his reappointment; a vote by the full Senate later confirmed the appointment, and he continued to serve in what he recently called "the most interesting and rewarding task of my working life."

Harwell Heats Office Building with Heat from BEPO Reactor

The Atomic Energy Research Establishment at Harwell, England, has put BEPO, the larger of its two experimental reactors, to work to heat an 80-office building at the site. The heating plant weighs eight tons and is no larger than a regular industrial furnace. The cost of the installation is reported to be $42,000. This is the first stage in the Ministry of Supply's plan to use, within practical limits, all the useful heat produced by the reactor. Two or three other buildings at Harwell may be similarly heated, with a predicted saving of 1,000 tons of coal a year.

This, the world's first atomic central heating plant, is a hot-water system. The constant hot water that flows through the pipes is obtained by placing a heat exchanger in the outlet air duct of the reactor's air-cooling system. Here there is a by-pass fitted with a damper that can be adjusted to vary the proportion of the air flow passing through the heat exchanger. Hot water from the exchanger is then circulated in a closed circuit by a small pump to a secondary water-to-water heat exchanger. This supplies hot water for space heating and domestic hot-water supplies.

At present, the air temperature at the primary heat exchanger is 135° F, and the water itself is heated to 130°. Later this year, when modifications to the reactor have been completed, these temperatures will be substantially increased.

The heat output designed for the first building is 1,000,000 Btu/hr, but for the final installation the maximum output will be 7,000,000 Btu/hr. The total floor area now being heated is 32,000 sq ft, and the volume of space is 330,000 cu ft.

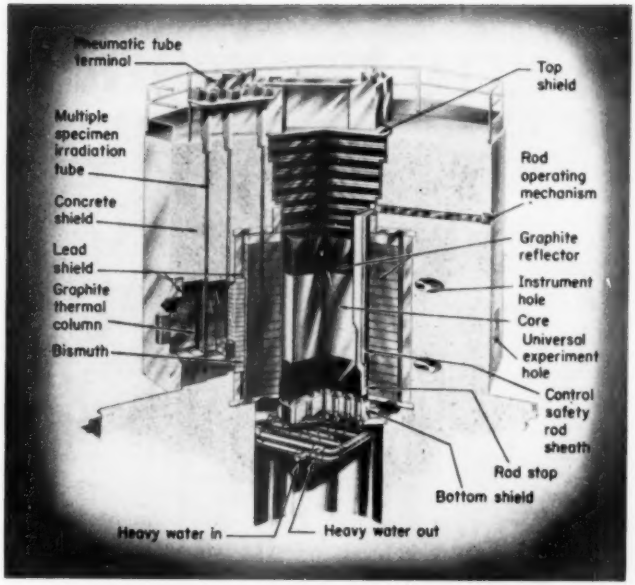
When the system is extended to include other buildings, no other heat-exchanging apparatus will be required, and it will be necessary only to connect the piping.

Squibb & Sons Set Up Radioisotope Laboratory

E. R. Squibb & Sons have set up a radioisotope laboratory at their research laboratories in New Brunswick, N. J., according to a recent announcement by A. F. Langlykke, director of research and development. The new facility will function primarily as a service unit to assist other research departments.

The work of the isotope laboratory, which is directed by Paul Numerof, who served at Los Alamos during World War II, will include extensive use of tracers to determine the action of new drugs. A project already underway is a study of the growth processes of the micro-organisms that produce penicillin and streptomycin. The work is directed toward an indication of ways to increase the yield of these antibiotics in manufacturing.

Want a Low-Cost, Low-Power Research Reactor?



DETAILED INFORMATION on the low-cost, low-power reactor shown here was recently released by North American Aviation, Inc. To be made available for private use, this reactor was designed under contract with the Atomic Energy Commission. If construction of the pile is authorized by the AEC, the cost would be about $1-million. Authorization for this expenditure was made in AEC's 1951 budget with $1.4-million set aside for a "research reactor, location unknown."

Further development work is now being carried out on components at North American's Atomic Energy Research Dept. at Downey, Calif., under the direction of Chauncey Starr. This is expected to be completed by July 1.

The design study took nine months and was actually completed in late 1949. If the reactor is built, construction would probably take about a year and a half. Start-up and testing might require an additional six months.

This type of reactor is particularly suited for use in industrial and institutional research and for training of scientists and engineers in reactor operation. One big advantage is the lack of any major waste disposal problem. The reactor core is contained in a tank and the fuel does not have to be processed for 10 years.

About 450 tons of concrete would be used in the reactor which has the form of an octagonal prism, 19 feet in diameter and 11 feet high.

Design Data for the Low-Power Reactor

Power	
Heat:	Design, 160 kw; maximum, 200 kw
Material and Amounts	
Fuel:	Enriched uranium
Moderator:	Graphite
Core tank:	Gastight aluminum container
Reflector:	Graphite (34 tons)
Shield:	Steel and concrete (450 tons)
Primary coolant:	Heavy water
Secondary coolant:	Light water
Fertile material:	None
Fuel	
Average cycle time:	10 years
% burnup per cycle:	5% (10 years at 2,000 hr/yr, at 10^{12} flux)
Neutron Flux Density	
Thermal, average:	10^{12} n/cm²/sec
Fast, average:	0.07×10^{12} n/cm²/sec
Dimensions	
Core:	Hexagonal prism, $4\frac{1}{2}$ ft diam. $\times$ $4\frac{1}{2}$ ft high
Reflector thickness:	30 in.
Shield thickness:	Steel, 6 in.; heavy concrete, about 3 ft
General	
Control method:	Vertical control rods in the form of cadmium and aluminum sandwiches
Safety characteristic:	Self-controlling due to negative temperature coefficient

AEC Patent Board Makes First Award

The Patent Compensation Board of the Atomic Energy Commission has awarded $7,500 to Cyril E. McClellan of Glen Burnie, Md., for development of an apparatus and method useful in isotope separation. This is the first award made by the Board since it was established in April, 1949. Six applications for compensation have been considered since that time, but no award was allowed in the other cases.

Mr. McClellan, who is an engineer employed at the Westinghouse Electric Corporation's plant in Towson, Md., based his application on his design of an apparatus and method useful in separating isotopes of different mass by application of the principle that the time of flight of ions of the same charge varies with their respective masses.

The Board stated that the evidence "supports the conclusion that the method is operative." It added that, while a method employing the same

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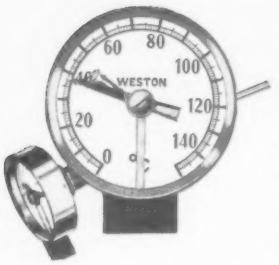

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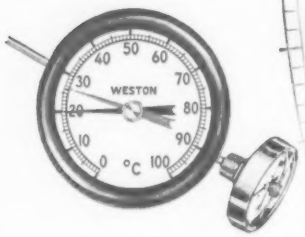

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principles has been experimentally tried as a separation process and abandoned by the AEC and a similar method and apparatus, improved by the Commission staff, is being used in research measurements, "no precise evaluation of the potentialities of the applicant's method and apparatus or measure of its importance is possible."

Take Applications for '52–'53 Graduate Study

The Oak Ridge Institute of Nuclear Studies is now receiving applications for Atomic Energy Commission Graduate Fellowships in Radiological Physics for the 1952–53 school year.

The fellowships are awarded for study at two training centers: one at the University of Rochester in cooperation with Brookhaven National Laboratory, and the other at Vanderbilt University in cooperation with Oak Ridge National Laboratory.

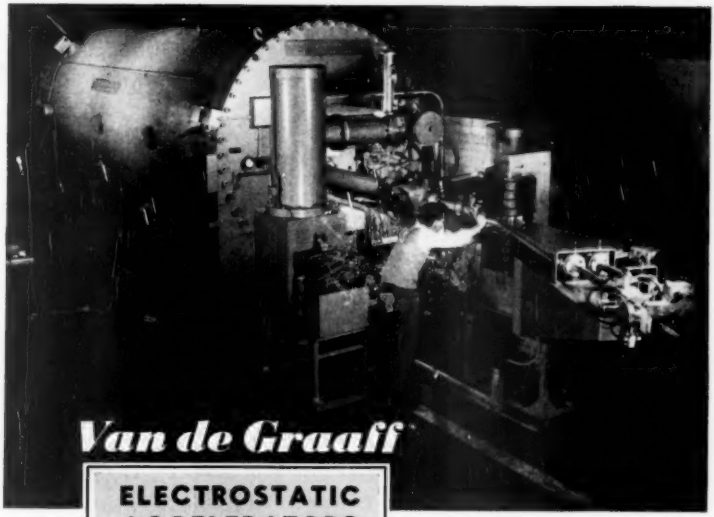
Appointments are made for one year for specialized training in radiological physics. The annual basic stipend is $1,500. An additional $500 is allowed for a wife and $250 for each of two dependent children, making a maximum stipend of $2,500 annually. Applications must be in the hands of the Institute by March 1. Only U. S. citizens will be considered.

For further information, address the University Relations Division, Oak Ridge Institute of Nuclear Studies, P. O. Box 117, Oak Ridge, Tenn.

Pratt & Whitney to Build Second Aircraft Reactor

The Air Force last month announced it has contracted with the Pratt & Whitney Aircraft Division of the United Aircraft Corporation, East Hartford, Conn., to undertake the building of a nuclear reactor to power a contemplated "atomic aircraft." This is the second such reactor ordered by the Air Force. No information on delivery dates or the amount of the contract was made known.

Air Force officials added that this contract in no way affects the work being done by the General Electric Company in connection with an Air Force contract let last year to develop a nuclear power plant for an airplane to be built by the Consolidated Vultee Aircraft Corporation. The two proj-



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The instrument illustrated is the four-million-volt positive-ion accelerator built for Duke University.

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Brookhaven National Laboratory — Accelerator Project, Chemistry Department
Duke University — Physics Department
Ecole Polytechnique (Paris) — Physics Department
General Electric, Hanford Works — Nucleonics Division
Massachusetts Institute of Technology — Physics Department
Oak Ridge National Laboratory — Physics Department, Chemistry Department
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ects are not competitive, they said, but are merely "two different technical paths to the same end."

Wright A. Parkins, Pratt & Whitney's engineering manager, and Perry W. Pratt, United Aircraft's assistant chief engineer, will direct the technical development of the project.

Program Announced for Scintillation Counter Talks

The speakers and tentative program of the Symposium on Scintillation Counters to be held at the Shoreham Hotel in Washington, D. C., on January 29-30 were announced last month by G. A. Morton, chairman of the planning committee.

The symposium will be divided into four sessions, with papers and participants as follows:

Session I (L. S. Taylor, chairman)—*Two new photomultipliers for scintillation counting*, by RCA Laboratories; *Some observations on pulse-height resolution and photosensitivity*, by R. Swank; *Scintillation counter spectrometry*, by P. R. Bell; and *After-pulsing in photomultipliers*, by D. W. Mueller.

Session II (H. Kallman, chairman)—*High-energy particles and the scintillation counter*, by L. F. Wouters; *Crystal and liquid phosphors*, by G. T. Reynolds; *Neutron detecting phosphors*, by J. C. Schenck; and *Temperature effects in phosphors*, by S. H. Liebson.

Session III (P. R. Bell, chairman)—*Emission time of secondary electrons*, by R. R. Law; 6BN6 *Fast coincidence circuit*, by J. Marshall and J. Fischer; and *Time measurements with coincidence circuits*, by S. DeBenedetti.

Session IV (J. B. H. Kuper, chairman)—*Performance of pulsed multiplier*, by R. F. Post; *High-speed oscilloscope*, by C. H. Smith; *Pulse height selector problem*, by G. G. Kelley; and *An analysis of new electronics required for optimum use of scintillation counters*, by W. A. Higinbotham.

Information on attendance can be obtained from R. W. Johnston, Radiation Instrument Branch, Atomic Energy Commission, Washington 25, D. C.

Radiological Health Courses Offered by Health Service

Free, two-week training courses in radiological health are being offered to qualified applicants by the Public Health Service in Cincinnati, Ohio.

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offered to professional people who are primarily concerned with radiological-health problems in their respective fields. Candidates should have a degree in medicine, engineering, physical science, or biological science, and have had experience in public-health work.

The basic courses, as scheduled, will be given during the periods January 21–February 1, March 10–21, and April 21–May 2. This course provides a two-week period of training in the basic theory of radiation and radiation-detecting instruments, shielding, etc.

Two intermediate courses have been scheduled for the periods February 4–15 and May 5–16. For those having completed the equivalent of the basic curriculum, this course provides two weeks' training in the maintenance, of radiation-monitoring instruments.

Applications and additional information can be obtained by addressing the Chief, Radiological Health Training Section, Environmental Health Center, 1014 Broadway, Cincinnati 2, Ohio.

Reactor School Applications due March 1

March 1 is the deadline for filing applications for the 1952–53 session of the Oak Ridge School of Reactor Technology. The year-long course, which starts September 8, provides advanced specialized training to selected engineers and scientists who will engage directly in the AEC's reactor development program (NU, Feb. '51, p. 87).

The course is of particular interest to industrial organizations that seek such training for experienced engineers in their employ. Students remain on the company's payroll while training. The course is classified, and all students must have security clearance.

For applications, write the Director, Oak Ridge School of Reactor Technology, P. O. Box P, Oak Ridge, Tenn.

IN BRIEF

• February 4 is the starting date for the next Radioisotopes Training Course to be given at the Oak Ridge Institute of Nuclear Studies. It is the twenty-fifth of these courses to be given since they were started in 1948.

• *Work has begun on processing units of the new Atomic Energy Commission plant at Rocky Flats, Colo.*

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• An atomic-energy laboratory for $29.70 (reduced from $49.50) was on the market for the Christmas trade last month. Loeser's, a Brooklyn department store, had a one-day sale of this A. C. Gilbert "toy" that includes a Geiger counter, cloud chamber, alpha, beta, and gamma sources, and other atomic gadgets for the junior nuclear scientist and his father.

NUCLEAR NEWSMAKERS

B. W. Sargent, who recently resigned as assistant director of the physics subdivision of Canada's atomic energy project, has been appointed head of the physics department of Queen's University, Kingston, Ont.

C. S. Shoup replaces **Edward H. McCrady,** who resigned, as chief of the biology division of the AEC's Oak Ridge Operations Office.

Warren Winsche has resigned from Brookhaven National Laboratory, where he was assistant chairman of the department of reactor science and engineering, to work for E. I. duPont de Nemours & Co. on the AEC's Savannah River project.

Lawrence Hafstad, director of the AEC's division of reactor development, has been named chairman of the Professional Group on Nuclear Science of the Institute of Radio Engineers which met last month at Brookhaven National Laboratory. The group selected as its vice chairman **J. B. H. Kuper,** chairman of Brookhaven's Instrument and Health Physics Department.

Elmer E. Stickley, formerly with the Pittsburgh Plate Glass Co., has joined the staff of the medical department of Brookhaven National Laboratory. As first physicist in the physiology division of the department, Dr. Stickley will correlate measurements of effects of radiation on living cells.

MEETINGS

Third Scintillation Counter Symposium—Shoreham Hotel, Washington, D. C., Jan. 29–30

American Physical Society—New York, N. Y., Jan. 31–Feb. 2

American College of Radiology, Annual Meeting—Palmer House, Chicago, Ill., Feb. 8

19th Annual Conference of Teachers of Clinical Radiology—Palmer House, Chicago, Ill., Feb. 9

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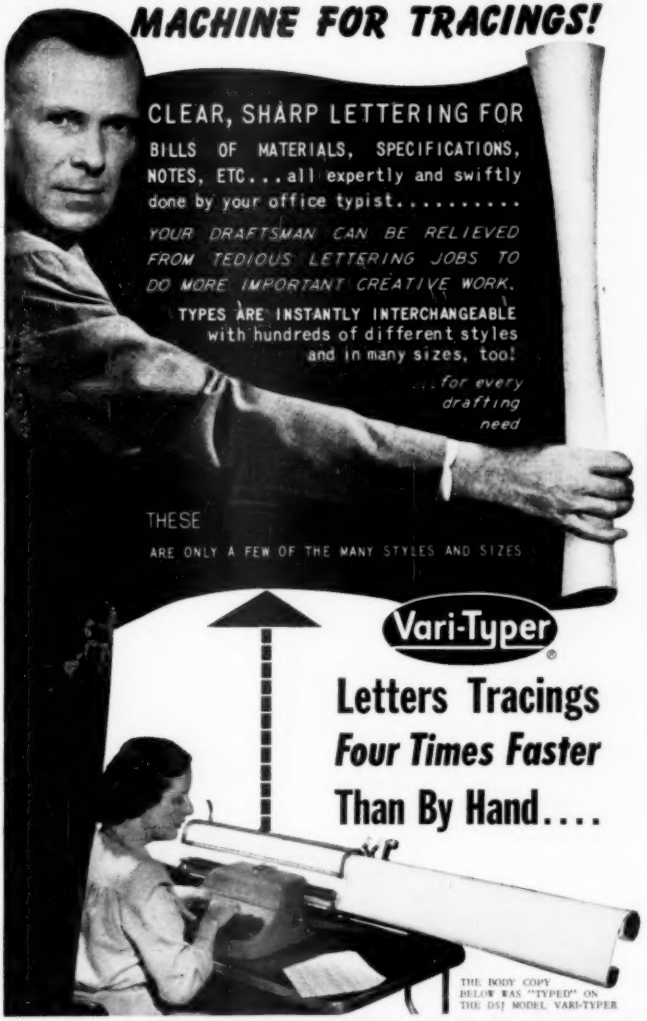
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LETTERS

G-M Counter for Liquids

DEAR SIR:

We notice with surprise that an article by G. Rose and E. W. Emery, on page 5 of the July, 1951, NUCLEONICS, states that the particular type of G-M counter which was the subject of the article is described as being "now manufactured as Twentieth Century Electronics type M6," full details and address being given. No mention is made of any other manufacturers in spite of the fact that Nucleonic & Radiological Developments Limited (originally Alltools Research Laboratory) were the original collaborators with Mr. N. Veall of the Medical Research Council in the design and supply of these counters.

Actually, these tubes, known as MRC-1, have never been out of production since they were originated by us and have in fact been advertised from time to time in your journal under our present name.

ARNOLD GRAVES
Director of Research
Nucleonic & Radiological Developments, Ltd.
London, S.W. 3, England

Australia's Particle Accelerators

DEAR SIR:

I have just seen the note "Australia's Accelerator Nearing Completion" in the August, 1951, NUCLEONICS and would like to advise you that it is in error. The program of the Research School of Physical Sciences of the Australian National University involves the construction of two machines.

The first is conventional Cockcroft-Walton rectifier equipment to provide particles of energy up to 1.25 Mev, and it is this machine that will be erected before the end of 1951. The second, and much larger, machine is the cyclo-synchrotron designed by Professor M. L. Oliphant and described in *Nature* **165,** 466 (1950). This machine will be constructed first as a synchrocyclotron to provide protons of energy up to 240 Mev and at a later date will be converted to a bevatron to yield protons of energy up to 2 Bev.

The steel for the 1,400-ton magnet of the latter machine has been rolled and is now being machined. Operation as a synchrocyclotron is not expected before 1953, and a further year or two may be necessary to solve the technical problems associated with the homopolar generators and the r-f system required to convert the machine to the higher energy.

Apparently in the report you received, these two machines were confused; hence the mistaken reference to a 1-Mev cyclosynchrotron.

E. W. TITTERTON
Professor of Physics
The Australian National University
Canberra, Australia

CPS vs CPM*

TO THE EDITOR:

Medical research and clinical records are probably more often vitiated by 300% blunders than by 3% errors, or maybe even 30% errors. Steinmetz has advised that all computations be done three times. They should be done once by mental arithmetic, rounding off all values to make them easy to handle (this gives one the order of magnitude of the result and prevents those big blunders), then they should be repeated using a slide rule, which gives precision to a fraction of a per cent. Lastly they should be done by five-place logs or better, which gives a precision seldom warranted in medical work because our primary data seldom have probable errors as small as 1%.

The more factors we have, the more chance for blunders. Factors of 10 are, however, much less bothersome than others. It is a pleasure to live in the U. S. where money is in the decimal system. Why we have not been courageous enough to get rid of the ancient Chaldean 60 in our time units is not easy to see—or better say, is hard to condone. The surveyors did finally get rid of their chains, rods, yards, and inches, and for years now have worked in feet and decimal multiples and submultiples of feet—even though the attitude of civil government still keeps us loaded with the acre, an area which when square has not got sides that come out even for any unit. "If I were king," I'd sure reform the clock and the calendar!

Now, the definition of the curie is 3.700×10^{10} disintegrations per second. Therefore all our radioactivity computations start or end with events-per-second. It has long been the habit of those who are using counters for clinical or biological investigations to measure their times in minutes and to reduce their data to counts per minute. Many record counts per minute just from habit, or by imitation. "Monkey see, monkey do." Some do it quite thoughtfully, believing that the integral numbers they have to deal with in counts per minute are more convenient than the decimal fractions that have to be preserved for sufficiently precise recording in counts per second. They feel that this avoidance of many decimals more than makes up for the regular introduction of an extra factor of 60 in their computations.

Without conducting an observational experiment (which is almost never done), one cannot be sure what is the optimum way to use one's own mind, much less anybody else's. But it is easy to observe one's own emotional reactions, and I confess that that extra factor of 60 exasperates me. I don't mind recording 0.16 cps, or not very much. And if the labor piles up, I can get shut of it by thinking, rather, 16 counts per 100 sec.

Now that scintillation counters are being perfected and made more readily available, it seems likely that those who are measuring gamma rays in counts per minute will be recording columns of thousands, and it will often be the fellows like me who keep their records in counts per second who have the lesser labor.

I think I can present this essay, not as an apology for counts per second, but as a crusade to promulgate it.

R. R. NEWELL, M. D.
School of Medicine
Stanford University
San Francisco, California

* This is an invited letter. The editors invite further comment from readers.

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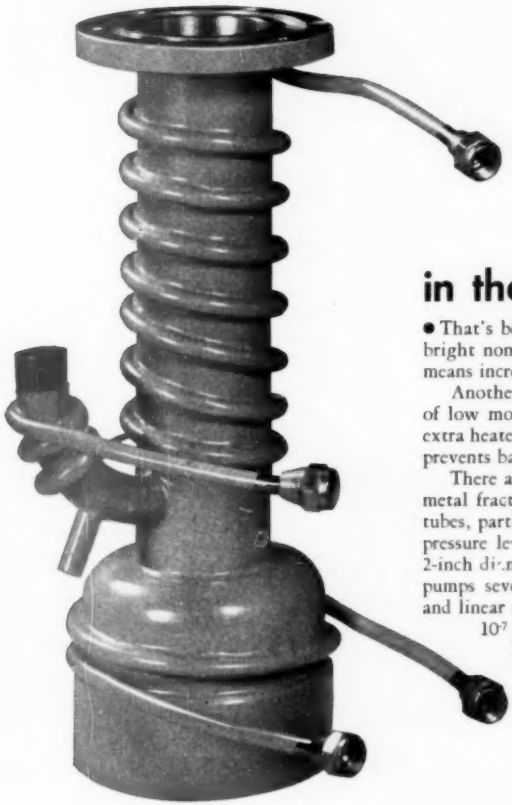

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There are other design features too that make this series of all-metal fractionating pumps ideal for evacuation of large electronic tubes, particle accelerators, and other devices requiring an ultimate pressure less than 10^{-5} mm Hg. MCF pumps range in size from a 2-inch diameter model suitable for exhaust of cathode-ray tubes to pumps several feet in diameter used on giant synchro-cyclotrons and linear accelerators. The ultimate vacuum of these pumps is 5 x 10^{-7} mm Hg at 25°C without cold baffles or traps.

If you would like complete technical data on the series of MCF diffusion pumps, simply write to ***Distillation Products Industries,*** Vacuum Equipment Department, 781 Ridge Road West, Rochester 3, N. Y. (Division of Eastman Kodak Company).

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PRODUCTS AND MATERIALS

Leak Locator

Radio Corp. of America, Scientific Instruments Section, Camden, N. J. The type EMV-7 leak locator is a hydrogen-sensitive, ionization-type instrument designed for vacuum-system work. It is capable of detecting leaks as small as 10^{-5} liter-microns of hydrogen per second, it is claimed. In a mixture of gases having a manifold pressure of 10^{-2} mm Hg, the device can detect a partial hydrogen pressure of 4×10^{-7} mm Hg. A sealed-off high-vacuum-gage tube which responds only to hydrogen, and is unaffected by other residual gases, is the heart of the device.

Double Pulse Generator

Berkeley Scientific Co., Sixth and Nevin Aves., Richmond, Calif. The model 903 produces pulses that are independently and continuously variable in amplitude and width. Amplitude of negative pulses is variable from 200 volts maximum into a 1,000-ohm load and 10 volts maximum into a 50-ohm load; for positive pulses the range is from 50 volts maximum into a 1,000-ohm load and 2.5 volts maximum into a 50-ohm load. Separation of the pulse pairs is variable from 0 to 10 μsec. The rise time of the pulses is 0.035 μsec, and the decay time less than 0.15 μsec. Pulse width is individually variable in the range 0.1–1.8 μsec. The repetition rate of either single pulses or pulse pairs is internally controllable from 1 to 1,000 pulses per sec. Single-cycle pulses or pulse pairs may be obtained.

High-Voltage Supply

Nuclear Research Corp., 2563 Grays Ferry Ave., Philadelphia 43, Pa. The model VS-2A regulated high-voltage supply provides continuously variable voltage in the range 300–2,500 volts, d-c. With a 1.0-ma load, the output voltage at 2,500 volts is stabilized to ±0.01%; with a 100-μa load, the stabilization at that voltage is said to be ±0.001%. Maximum ripple under maximum load conditions is less than 0.1 volt at 2,500 volts, d-c, it is claimed. The 0–0.5-ma meter reads in volts with an accuracy of ±2%.

Laboratory Monitor

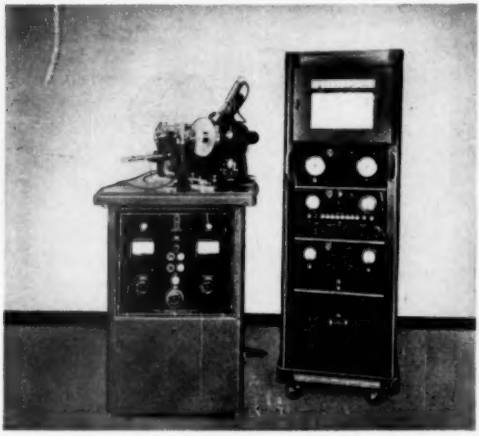
Nuclear Instrument and Chemical Corp., 229 W. Erie St., Chicago 10, Ill. The model 1615A monitor for alpha, beta, and gamma detection indicates activity on a count-rate meter in five ranges; the lowest range has a minimum of 100 cpm and a maximum of 500 cpm, and the highest a maximum of 50,000 cpm. A switch is provided for selection of 2%, 5%, or 15% statistical accuracy on each range.

Mass Spectrometer

Consolidated Engineering Corp., 300 N. Sierra Madre Villa, Pasadena 8, Calif. The model 21-401 mass spectrometer is designed for analysis of mixtures of gases and light liquids, as well as for the determination of ratios of stable isotopes. For mixture analysis, the instrument has a mass range of 2–100, with automatic scanning and recording of spectra in the mass range 12–100. About 15 or more complete runs can be made in 8 hr. The spectra are recorded on a strip-chart recorder; automatic attenuation of peak magnitudes provides a dynamic recording range of 300,000 to 1. For isotope-ratio work, the ratio is obtained directly by an automatic null-balancing method, and is recorded. Within sensitivity limitations, ratios in the range 0–1.0 can be measured. The first three decimal places are obtained from decade dials, the last three from the inked record.

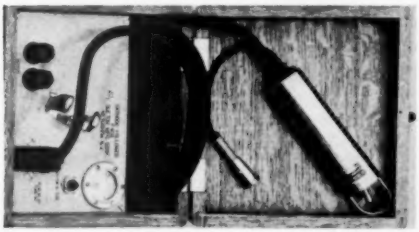
Beta Counter

Nuclear Development Laboratory, PO Box 7034, Kansas City, Mo. The model B1E mica-end-window G-M counter is designed for counting soft betas. The window has a thickness of 1.6 mg/cm² and a 1⅛-in. effective diameter. Window thicknesses as high as 5.0 mg/cm² can be obtained. Threshold is at 950 ± 25 volts; plateau length is 300 volts with a 3% slope per 100 volts. With a 1-in. lead shield, the background is 15 cpm. Dead time is 75 μsec; beta efficiency is said to be better than 99%. The normal filling gas is argon plus a quenching mixture at 11 cm Hg; special fillings can also be obtained. Also obtainable is a model with a threshold of 800 ± 25 volts.



X-Ray Spectrometer

North American Philips Co., Inc., Research and Control Instruments Division, 750 S. Fulton Ave., Mount Vernon, N. Y. The complete assembly of this recording X-ray diffraction spectrometer consists of an X-ray diffraction unit, a wide-range G-M goniometer, and a strip-chart recorder. The instrument is designed for X-ray powder-diffraction work, and fluorescence analysis. The X-ray-tube voltage is continuously variable up to 60 kv at 50ma. The G-M counter goniometer is designed to scan and analyze X-ray diffraction spectra by divergent-convergent beam-focussing geometry. It provides an accurate measurement of angles from −38° to +180°, with a useful X-ray diffraction range of 38°–165°. The goniometer scanning has a horizontal axis; angle of inclination of specimen face to the horizontal can be varied in the range 0°–80°.



Cathode Follower

Gulton Manufacturing Corp., Metuchen, N. J. The model F407 cathode follower is designed to terminate piezoelectric pickups and other high impedance devices into standard electronic equipment. The frequency response covers the

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Dosimeter Film

E. I. duPont de Nemours and Co., Wilmington 98, Del. The dosimeter film described in "Cross Sections" [NUCLEONICS **9**, No. 4, 74 (1951)] will be marketed as type 558 Dosimeter Film. It is a combination of types 508 and 1290 (Adlux). The readings possible with this film cover the range 15 mr to 750 r.

Omission

Kewaunee Mfg. Co., Adrian, Mich. was not listed in the NUCLEONICS Buyers' Guide, published in November, 1951, due to an oversight. The company manufactures fume hoods.

Standard Samples

Radioactivity Section, National Bureau of Standards, Washington 25, D. C. Standard low-activity samples of P^{32} and I^{131} are now available. Contained in flame-sealed sterilized glass ampules, the active isotope is held in about 3 ml of dilute carrier solution. The exact disintegration rate per milliliter as of the zero date is noted; the rates are roughly 100,000 dps/ml. Radiophosphorus is distributed during March and September, and radioiodine during January and June; a limited supply is available for immediate distribution for emergency purposes.

Scaling Tube

Ericsson Telephones Ltd., Nottingham, England. This tube, model GC10A, is a gas-filled cold-cathode discharge tube that has been designed as a scale-of-ten counter. Resembling an ordinary radio tube, it has a flat central anode near the end of the tube, around which thirty identical wires are symmetrically placed. For operation as a scale-of-ten tube, the anode is connected through a current-limiting resistor to about +400 volts. The cathodes are arranged in rings of nine. A normal glow discharge takes place between the anode and one of the cathodes. By changing the potentials on the cathodes, each input pulse transfers the glow 36° clockwise. Eventually the pulse reaches the output cathode

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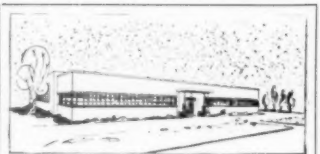

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where it is visible from the end of the tube. The location of the glow provides a means of interpolation between scale-of-ten outputs. The maximum repetition rate is 600 pulses per second. The life of the tube is estimated to be 10,000 hr. A miniature model, the GC10M, is available; the model GC12A has external connections on the cathodes so that a voltage can be developed across an output resistor when the glow rests on the corresponding cathode.

LITERATURE AVAILABLE

Test equipment. Illustrated bulletin GEC-1016 describes measuring and production-line testing equipment. *General Electric Co., Schenectady 5, N. Y.*

Connectors. Bulletin SIM-1 is an instruction and service manual for AN-"M" connectors. *Cannon Electric Co., PO Box 75, Lincoln Heights Station, Los Angeles 31, Calif.*

Counter tubes. Specification sheets give data on G-M tubes. *Nucleonic and Radiological Developments Ltd., London, S. W. 3, England.*

Microscopes. Handbook discusses the use and care of the microscope. *E. Leitz, Inc., 304 Hudson St., New York 13, N. Y.*

Filter paper. Catalog 70 gives information on use and specifications of analytical filter papers. *Schleicher and Schuell Co., Keene, New Hampshire.*

Emergency showers. Bulletin 30 shows and describes emergency and decontamination showers. *Logan Emergency Showers, Inc., PO Box 111, Glendale, Calif.*

Rubber pails. Bulletin 540 describes synthetic rubber pails for handling acids. *Andrew Technical Service, 3805 N. Clark St., Chicago 13, Ill.*

Precision potentiometers. Catalog N-L gives data on precision wire-wound potentiometers. *DeJur-Amsco Corp., Industrial Division, 45-01 Northern Blvd., Long Island City 1, N. Y.*

Radioactivity instruments. Illustrated price list gives information on line of instruments and accessories. *Radiation Counter Laboratories, Inc., 5122 W. Grove St., Skokie, Ill.*

Insulation tester. Folder describes English-made portable test instrument. *Herman H. Sticht Co., Inc., 27 Park Place, New York 7, N. Y.*

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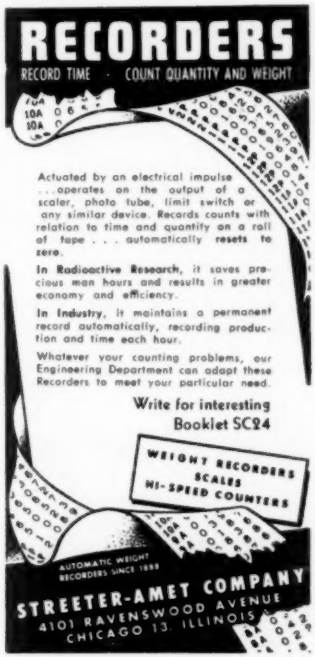
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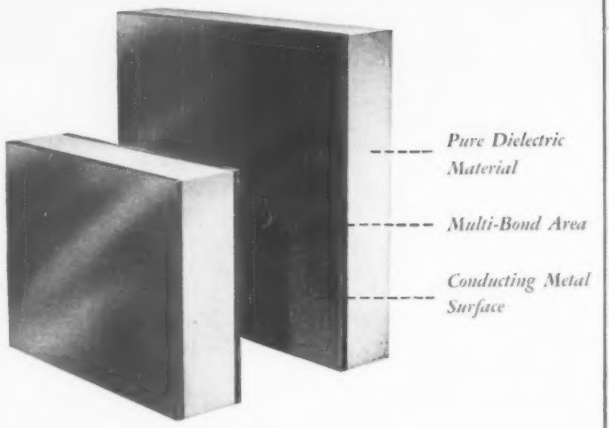
CHEMELEC MULTI-BOND



Metal Faced TEFLON*

● Here is the answer to the bonding and hermetic sealing of dielectric materials to metal components.

Chemelec Multi-Bond is metal faced pure or filled TEFLON, produced by an exclusive (patents pending) method of uniting fluorocarbon resins and metals with an interlocking bond unaffected by severe mechanical shock, vibration and unequal rates of thermal expansion.

The bond is micro-crystalline in structure and gradually changes from dielectric to metal, the conducting metal surface being applied by electro-deposition or other conventional means.

Facing metals include practically all the ferrous and non-ferrous metals, the ferro magnetic group and the precious metals.

Sheets are available, metal faced on one or both sides, in thickness from .034 to 1.75 in. and in sizes up to 36 in. square.

Write for Bulletin MI-424.

*du Pont's trademark for its tetrafluoroethylene resin.

UNITED STATES GASKET COMPANY

FLUOROCARBON PRODUCTS DIVISION

660 N. 10TH STREET, CAMDEN, N.J.

FOREMOST FABRICATORS OF "TEFLON" AND OTHER FLUOROCARBON PLASTICS

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Two Scalers for the Price of One—$475.00

RCL TWIN SCALER—RCL Mark 13 Model 6

For those laboratories with a Budget Problem, Radiation Counter Laboratories, Inc., offers two scalers for the price of one. This method of counting, using two detectors and a single electronic circuit, has been extensively used on the European continent in order to save laboratory space and money. RCL has designed a Higinbotham Binary Scaler with two input connectors, two scales of 16, and two recorders. Each scale of 16 and its recorder operates independently from the other, using a single high voltage power supply. Counting rates up to and in excess of 20,000 counts per minute can be independently registered on each Veeder-Root recorder.

When more rapid recording of counts is desired from a single detector, a switch is simply thrown, placing the two scales of 16 in series, making a single Higinbotham scale of 256 totalizing on one register. The throwing of this switch also electrically disengages the second input connector.

The single high voltage power supply employs two separate regulating circuits so the voltage available at each Geiger-Mueller tube may be regulated to the desired value. A switch enables one to check the voltage on first one and then the other G.M. tube. This instrument is competitively priced, yet built of the finest components. Due to the demand for this RCL Twin Scaler, you should order now for early delivery.

SPECIFICATIONS

1. Two Higinbotham scales of 16, or one scale of 256.
2. Two 82-805 input connectors.
3. Resolving time of approximately five microseconds.
4. Input capacity less than 10 mmfd.
5. Voltage variable from 500 to 2,000 volts permitting all types of Geiger tubes to be utilized.
6. Voltage regulation: Such that a one percent change in line voltage changes counter voltage by less than 0.01 %.
7. Chassis mounted sensitivity control continuously variable from 0.2 to 5 volts, preset at factory at 0.25 volt.
8. Two Veeder-Root six digit recorders.
9. Power requirements: 200 watts at 105–125 volts, 60 cycle A.C.
10. Two timer connections at rear from standard 110 volt sockets.
11. Standard cabinet, 21¼ in. x 15 in. x 10¼ in., copper plated and finished in attractive smooth grey hammertone.
12. All hardware is stainless steel where possible.

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RADIATION COUNTER LABORATORIES, INC.

5122 West Grove Street — Skokie, Illinois

nuclear *Reactor Instrumentation*

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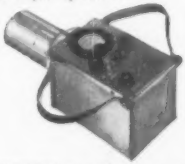
NUCLEAR'S Neutron Thermopile has made an important contribution to simple high-level slow neutron instrumentation. It is used within the reactor for monitoring and control purposes — and is the only neutron "thermometer" commercially available to pile operators.



"NEUT" for Measurement of Fast Neutrons

NUCLEAR Model 2714 "Neut" ion chamber type survey meter is used for health monitoring near reactors . . . measuring fast neutron flux in a gamma ray field. It, too, is the only commercially manufactured instrument of its type.

Four ranges of gamma and neutron radiation rates are provided. Interchangeable ion chambers allow measurement of gamma-plus-neutron flux and gamma flux only, thereby permitting determination of neutron radiation.

TECHNOLOGISTS in the field of atomic reactor construction and operation can look to NUCLEAR for expert advice, assistance and equipment in all phases of reactor instrumentation and control. NUCLEAR has a background of experience in this field, represented in part by scientists who participated actively in the instrumentation of the early reactors, and by a continuous research and development program which has evolved a number of commercially manufactured instruments, of which the thermopile and "Neut" are representative examples.

In addition to instruments for atomic reactors, NUCLEAR'S complete matched line of survey, counting, and analysis instruments for use with reactor products enables pile operators to secure proven precision instruments for every need from a single source. A variety of radioactive chemicals is also marketed by NUCLEAR.

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